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ADVISORY GROUP FOR AEROSPACE RESEARCH & DEVELOPMENT

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Problems of the Cockpit Environment

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NOVEMBER 1968

(EXTENDED SUMMARIES)

NORTH ATLANTIC TREATY ORGANIZATION

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NORTH ATLANTIC TREATY ORGANIZATION

ADVISORY GROUP FOR AEROSPACE RESEARCH AND DEVELOPMENT

(ORGANISATION DU TRAITE DE L'ATLANTIQUE NORD)

PRESENTS

THE AVIONICS PANEL XVIth TECHNICAL SYMPOSIUM

PROBLEMS OF THE COCKPIT ENVIRONMENT

In cooperation with the AGARD:

AEROSPACE MEDICAL PANEL
FLIGHT MECHANICS PANEL
GUIDANCE AND CONTROL PANEL

November 1968

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ACKNOWLEDGEMENT

The material in this publication has been produced directly from copy supplied by each author.

The Program Chairman would like to extend his appreciation to authors, editor, AGARD staff and other contributors for the preparation and presentation of material comprising this Symposium.

Printed by Technical Editing and Reproduction Ltd
Harford House, 7-9 Charlotte St. London. W. 1.

FOREWORD

The various technical activities of AGARD in the field of science and technology related to aerospace are carried out by permanent panels and committees composed of leading scientists and their contemporaries from each NATO nation.

The material presented in this publication is the extended summaries of papers delivered at the Avionics Panel's XVIth Technical Symposium covering "Problems of the Cockpit Environment". Emphasis has been placed on the "Crew in the Cockpit" viewpoint with contributions and representatives of the Aerospace Medical Panel, Flight Mechanics Panel and Guidance and Control Panel providing their specialists' views.

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* To be published later.

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* To be published later.

SPECIAL MAN/MACHINE CONSIDERATIONS FOR LARGE HELICOPTERS

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The helicopter with its unique hovering and low speed handling qualities requires special considerations in practically all aspects of cockpit design. At low speeds it must be conciously controlled in six degree-of-freedom by one pilot with four modes of control at his disposal. The pilot receives a variety of visual, motion and force cues which can radically change the degree of difficulty of the piloting task. This situation places a particular burden on the man/machine relationship.

This paper presents recent theoretical work and flight test experience on several Sikorsky aircraft. A number of significant factors, relating to pilot cues, aircraft configuration, and control system characteristics are drawn from these studies.

Control System Considerations

With the advent of the high speed helicopter and with the increasing size of the vehicle, very close attention must be paid to the design and production of the control system. Excessive hysteresis, lags, non-linearities and friction in a control system coupled with control or gust sensitivity problems will limit a vehicle's high speed capability. The first flight evaluation of the CH-53A's control system showed that it was plagued by nearly all of these control system ailments. A control system improvement program was undertaken during which servo's were reworked to reduce lags, and slop, and friction was reduced through hardware redesign. As a result of this program, and an AFCS improvement program the CH-53A today enjoys good handling qualities and considerable knowledge has been gained for future aircraft design.

To increase pilot comfort and improve upon flight deck lay-out, the side arm cyclic controller is a candidate for the replacement for the conventional helicopter cyclic control stick. Sikorsky conducted a quantitative flight evaluation of a side arm cyclic control stick on an S-61A helicopter with the particular interest of determining if a practical solution could be obtained for a mechanical control with the associated lags, friction and control characteristics. Quantitative evaluation using statistical techniques indicated that damping was the most significant variable tested, in that aircraft motion was greatly reduced as damping increased. As control power was increased, side arm stick motion decreased while aircraft motion increased. Moderate phase lag did not significantly affect pilot effort or aircraft motion, however, increasing hysteresis increased both pilot effort and aircraft motion. Comparison of the conventional stick and side arm controller indicated that when using the side arm controller, stick motion was the same or greater while aircraft motion was reduced. This test program proved the feasibility of a mechanical side arm controller system.

As flight time on high speed (above 150 knots) helicopters is accumulated, it becomes apparent that without any maneuvering force feedback loads can build up significantly as the aircraft reacts to gusts. At high forward speed without force feedback, the increased gust sensitivity and the greater distance which separates the pilot from the aircraft's center of motion, causes the operator to experience a considerably rougher ride under turbulent conditions. Experience of fixed wing aircraft, limited helicopter tests and preliminary helicopter simulation studies have shown that by introducing forces, into the longitudinal stick, a considerable improvement in maneuvering characteristics and overall high speed handling qualities can be obtained. Using the U.S. Marine/Sikorsky CH-53A as the test vehicle, Sikorsky entered into a further flight test program to determine which force parameter, or combination of parameters including "g", "q", angle of attack, pitch rate, stick gradient, and stick damping would produce desired handling characteristics. Early test indications show that the feedback of force proportional to aircraft pitch rate and stick position gradient as a function of dynamic pressure are the most desirable, however every possible combination of force parameters has not been examined. Pitch rate is favored over load factor because of the force coupling from collective motion and the 'nervous' stick resulting from simple load factor feedback.

Operating Environment Considerations

Since the helicopter has become larger in size, the pilot has been moved to a less desirable location relative to its center of motion, thereby affecting his ability to discern and utilize kinesthetic cues. The rear facing pilot in the Sikorsky S-64 for example, is well below the roll axis where during a rolling maneuver his translational acceleration cues are reversed from the normal situation. Because of the unusual visibility and sighting reference with the horizon this has not been a problem in VFR flying. However it might be expected that in IFR situations these reversed cues could cause control difficulty. In large helicopter designs now under consideration, the pilots are being located even further forward of the lower than the aircraft's center of motion. It is important as the helicopter becomes larger, that these poorer

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cues, and the higher inertial loadings on the pilots be examined closely to determine the extent that they affect the handling qualities.

Good pilot visibility is an essential aircraft attribute. In particular, the helicopter pilot requires considerably more forward and downward field of view especially during hover and confined area operations. The specific example of a crane helicopter is examined here because of its need to position externally attached loads with, in many cases, a high degree of accuracy. Crane applications which have been found to demand particular effort from the pilot and which have posed specific visibility problems are for example installation of smoke stacks aboard oceanliners, erection of transmission towers, and servicing offshore oil rigs. Experience gained in these operations indicates that it would be desirable to contain aircraft translational motion within a 4 inch circle. In order to approach this extremely tight criterion exceptional visual sighting of both the load and fixed references is most important. A rear cockpit, as in the case of the Sikorsky S-64 Crane, offers considerable advantage; however, even here typical downward visual sighting angles require that improved techniques are necessary to provide the pilot(s) better depth perception and vertical field of view.

The question of how much reliance on automatic stabilization any aircraft should have is a very important one when pilot capabilities are discussed. To properly assess it, the basic inherent characteristics must be well understood in terms of stability, controllability limits and divergence rates as well as the degree of pilot readiness and ability to handle an emergency or malfunction. Sikorsky has improved the design of the AFCS in order to obtain a minimum authority system but yet maintain an impressively useful feedback. Various existing longitudinal stability criteria have been examined regarding inherent stability feedback requirements, and malfunction characteristics. Existing criteria regarding malfunctions do not seem adequate particularily in the pilot reaction delay requirements and it is recommended that test data be generated to further define specifications.

Because helicopters are taking more active roles in tactical warfare, skycrane operations, and high speed rescue missions, more emphasis must be put on maneuvering characteristics and their effects on the pilots. The principal challenge today with these added demands is to maintain a good rapport between the pilot and his aircraft by providing a better cockpit control arrangement, by providing maneuvering and control motion force feedback, by providing better downward visibility and a better kinesthetic environment, and finally by providing an aircraft with sufficient inherent stability to overcome the type of malfunctions that have dealt crippling blows to mony of todays VTOL aircraft.

TRACKING ON DISPLAY VIBRATING AT 1-10 Hz

by

H.F.Huddleston

To be published later

OPTIMISATION OF THE COCKPIT ENVIRONMENT AND THE CREW-COCKPIT INTERFACE

by

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1 INTRODUCTION

Since the first aircraft was built there have been problems of cockpit environment and with the crew-cockpit interface. In the struggle to achieve even greater performance and effectiveness substantial progress has been made and continues to be made with the optimisation and integration of the aerodynamics, airframe, engines, controls and other ancillary equipment at all stages of the design and development, and of particular importance, in the project consideration stage. The last has become possible because the factors involved have been quantified, costed and equations produced which permit parametric studies to be made.

It is now widely accepted that further considerable improvement would be possible if we could achieve a rational integration of the man into the machine and much thought and effort has been devoted towards this over the last 10–15 years. However we are still a long way from our goal and such major questions as the number of crew members for a particular aircraft are still decided in a very arbitrary way often without rational analysis. Similarly the cockpit environment and the layout to be provided are rarely optimised.

The reason for this state of affairs is easy to see: at the present time we do not have realistic, consistent data which enable us to quantify the effects of the cockpit environment and layout on aircrew performance. In particular we cannot assess the operational penalties of failure to achieve an ideal state or arrangement and inevitably some compromises are necessary between providing this ideal and producing a viable aircraft.

The optimisation of the cockpit environment and layout can only be attempted on the widest basis. For example, for the successful alleviation of thermal stress it is necessary to consider crewroom, transit, waiting-at-readiness, flight, escape and survival conditions and with all these not only the design of the aircraft but ground and personal equipment as well. To arrive at a successful division of duties between crew members all possible sorties must be considered, how these will be flown, what weapons will be used and the effects of enemy actions.

In this paper we very briefly look at three problem areas. These are used to illustrate how the problems of cockpit environment and crew-cockpit interface are being tackled and to highlight certain necessary pre-requisites for a successful outcome.

2 COCKPIT ENVIRONMENT

2.1 Thermal effects

There is growing evidence from laboratory tests that there can be a significant mental impairment when aircrews are exposed to thermal environments which are nevertheless physiologically tolerable. If these results are applicable to the aircrew situation, then military aircraft are probably being operated at times with aircrew suffering a degree of mental impairment. Laboratory and operational field work is therefore required to determine the environmental limits for unimpaired mental performance of aircrew tasks and the penalties of operating outside these limits.

The problem is complicated by the wide variation in aircrew clothing that must be worn, so that any definition of environmental limits must be based on the man's micro-climate for different areas of the body influenced as they are to varying degrees by the general environment. It is complicated by the sometimes essential use of personal conditioning systems. These systems may use conduction, convection, radiation or evaporation to absorb the heat load on the man. They may use combinations of these channels of heat transfer in an attempt to secure thermal comfort. The relative fraction of heat lost by the man via any one channel will undoubtedly be different from that under normal conditions which may, in itself, alter the threshold of mental impairment.

The effect of a thermal situation on a subject is determined to some extent by his thermal history. Therefore having defined environmental limits for given situations, a method of integrating the effects of consecutive exposures to varying conditions must be developed.

A problem as complicated as this requires four approaches each dovetailed to the other, an investigation of the basic mechanisms whereby the man's mental performance is impaired, the painstaking development of clothing and equipment by specialists, the testing of the equipment under representative conditions with the subjects performing realistic aircrew duties, and above all, as indicated in para.1, overall consideration of the many pre-flight and post-flight conditions and equipment which affect aircrew thermal stress. In establishing realistic conditions collaboration between those operating today's aircraft and those working in the laboratory is absolutely vital.

2.2 Vibration

We are concerned here with vibrations in the frequency range 1–30 Hz which affects aircrew comfort, fatigue and performance. This frequency band is becoming increasingly obtrusive in large modern aircraft both on rough runways and in the air and in combat aircraft flying fast and low. This range is particularly critical because it covers the major body resonances and other physiological

disturbances. Furthermore considerable lateral vibration, which can be particularly disturbing, often accompanies the more usually investigated vertical vibration. Unfortunately, apart from the difficulty of predicting the vibration environment the designer is faced with a plethora of diffuse and often contradicting data in endeavouring to assess its effects on aircrew.

Our attack on this problem is on three fronts; the measurement of vibrations experienced in flight and the correlation of these findings with calculated predictions, the observation of pilots performance in accurate simulations of real aircraft performing real tasks whilst subject to various realistic levels of vibration and the detailed investigation of the mechanisms whereby the pilot's performance is affected.

3 CREW-COCKPIT INTERFACE

At the core of any study of the crew and cockpit as an entity is tbe fact that tasks have to be performed in the cockpit in order that the aircraft may accomplish its mission. A study of cockpit layout must start with the compiling of a list of all tasks in chronological order for each and every mission. Having done this, decided which tasks should be automated and divided the remainder into those which have to be performed continuously and those which occur at regular or irregular intervals, a preliminary assessment of crew complement can be made.

The next step is to allocate tasks between the crew complement, endeavouring to ensure that no crew member is either overworked or underworked. This brings us to the critical point of measuring work load and selecting a correct level for each crew member. This must be done in terms of mission success rates. It must not be forgotten that war is an extreme form of competition and the correct work load in a military aircraft may be far removed from that desirable in a civil aircraft.

Simulation may start with a very simple static cockpit model using paper instruments and provided sufficient care and imagination is used very useful results can be achieved, particularly in the sphere of cockpit layout and work-space. Experience then indicates that a large step forward is needed towards a far more complete simulation before worthwhile evidence of effectiveness can be achieved. Such a simulation should incorporate all the inputs which contribute to the crews work load and reproduce the snowballing effect on work load of possible errors and omissions by the crew or action by the enemy.

4 TOWARDS A SOLUTION

Other speakers will undoubtedly fill in a lot of the detail which has been omitted in this brief account. Nevertheless sufficient has been said to show that substantial progress will be made in the field of cockpit environment and crew-cockpit interface provided certain conditions are met and particular lines of approach adopted.

It is essential that those engaged in this work have a deep understanding of what lies behind the operational requirement. All missions, peace-time and war-time, must be understood and their relative importance established. The environment in which the crew will operate, in and out of the aircraft, must be known. The very closest liaison must be established between those producing future operational requirements, the engineers who have to offer different design compromises and the aircrews who have the experience of flying existing aircraft.

Our approach in the laboratory should be towards realism. We must study the crews performance at tasks as close to those met in the aircraft as possible under realistic conditions. We should establish by measurement and calculation the conditions and environment met in present and future aircraft. Whilst much of our experimentation will inevitably continue to be "ad hoc" we should wherever possible design such tests to yield more fundamental information to establish the mechanism through which the crews are affected and use the results as a guide to changes in cockpit layout instrumentation, controls, environment, etc. All to be again checked in a realistic simulation and ultimately in the air.

OBJECTIVE MEASUREMENT OF MENTAL WORKLOAD - APPLICATIONS TO THE FLIGHT TASK

by

J.W.H.Kalsbeek

To be published later

FLIGHT APPLICATION OF A THEORY FOR MANUAL CONTROL DISPLAY SYSTEMS

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INTRODUCTION

Current practice in the development of operational aircraft or space vehicle display systems is based largely on intuition and tradition backed by a qualitative understanding of the potentially useful control information. Instrument arrangements or integrated display formats are selected using this experience and background, and are then subjected to exhaustive and expensive development and comparison in simulators and, ultimately, in flight. The simulation process usually reveals shortcomings in the preconceived display systems which are overcome by progressively detailed modification and testing. Required modifications can be gross, such as display layout changes or additions to the display information; or they can be detailed changes in scaling and dynamic properties. Each progressive modification requires separate evaluation and assessment; and the selection of the best compromise system depends on these assessments. The entire procedure is time-consuming and costly. Until now, however, it has been entirely necessary.

The control display theory presented and applied here is aimed at nothing less than revolutionizing this art and making it into a science.

A. SCOPE OF THE THEORY

An analytical understanding of the various ways in which the pilot can function as a controller and instrument monitor is the basis for a theory of displays. Putting this understanding to work to achieve a detailed, quantitative, analytical description of the interactions among the pilot, the display system, and the vehicle will achieve direct and important savings in the display design/evaluation process.

The scope of manual control/display theory is illustrated in Fig. 1 in the context of a mission-oriented problem for which criteria for success and the forcing function environment are specified.

One or more controlled elements are represented by the dynamics of vehicle response to control. The display/control system for the vehicle with these response properties is to be synthesized so as to accomplish the mission with "acceptable" activity on the part of the pilot. Controlled elements are subjected to environmental and internal disturbances, d, such as wind gusts and hydraulic power supply fluctuations. A human operator will pilot the controlled elements through control actions, c, both by perceiving directly-controlled motions, m, and displayed or implicit environmental functions, i, such as intruding aircraft or terrain height along the intended flight path.

The entire display-pilot-control-vehicle combination is a multi-loop feedback control system. Usually a number of alternative feedback loop closures are possible. To identify the preferred loop closures, which in turn leads directly to the selection of preferred display quantities, the derived system performance and pilot workload measures are calculated and compared in iterative feedback analyses.

Central to this theory is the notion that display design is fundamentally a guidance and control problem which has interactions with our knowledge of human psychomotor activity. For example, control analyses using existing validated analytical descriptions of pilot behavior will yield directly the vehicle motion quantities which <u>must</u> be displayed to accomplish some given task. Furthermore, estimates of the average rate at which such displays <u>must</u> be sampled may also be calculated. In turn, the consequences of eye movements needed for sampling a given display arrangement can be estimated from available data from the discipline of engineering psychology. Expanding on this theme and properly implementing it leads to a practical procedure having as its primary outputs:

- the quantities or combinations of quantities which must be displayed to enable the specified mission phase or task to be performed. There is seldom a unique, necessary, and sufficient set in complex tasks, so there may be several possible sets of suitable display quantities.
- the pilot's appropriate dynamic behavior in acting on the displayed quantities
- performance and workload predictions for each system of displays evolved
- preferred signal allocation and arrangement of displays for each mission phase
- allocation of control functions between man and machine

The theory is applicable to separated, integrated, and panoramic displays. Guided by this theory, the preliminary design of a display system for vehicular control will finally become a rational procedure. Experimental studies will still be required to confirm analytical results, but the systems studied will be far fewer and the experiments more crucial and pointed. Finally, the existence of a practical theory will make feasible the proper role of analysis and simulation as corroborators and collaborators in the design process. Savings in both calendar time and money for the development of a display/control system for a critical mission should then be very substantial.

The development, refinement, and illustrative application of a perceptual model for the assimilation by the pilot, through the visual modality, of a multiplicity of segregated signal presentations was one of the subjects to which the research reported here addressed itself. The results afford an opportunity to account quantitatively for the most significant closed-loop effects of display scanning and sampling.

B. PROCEDURAL BASIS FOR THE THEORY

To illustrate the application of this theory to a practical problem, we use it to design a visual display system for manually controlled landing approaches on instrument flight rules in a jet transport aircraft guided by the standard FAA Instrument Landing System (ILS). Manual approach height and lateral position control are treated in multiloop dynamic analyses so as to select preferred variables for measurement and display. Closed-loop system performance and pilot scanning workload measures are also evaluated. The example concludes with the prediction of a preferred display arrangement. Comparison with FAA Category 2 instrument panel arrangements selected by two airlines operating the example aircraft shows the predictions to be remarkably accurate.

Although most of the elements which comprise the theory have been separately developed by a number of workers, only recently has it been possible to combine the elements into a usefully predictive tool for display design. The procedural stages are listed here in sequence; however, there is in practice much interaction and iteration among the stages. The schematic procedure used in the application is given in Fig. 2.

System Definition—in systems analysis terms (i.e., mission-based time- and frequency-domain representations of commands, disturbances, merit criteria, and system responses).

Loop Topology—mathematical empirical models for the elements in the closed-loop task, such as: pilot dynamic response, multiloop vehicular dynamics, display scanning effects, alternative feedbacks available on the displays, control/display associations, and inner-loop/outer-loop display associations.

Loop Closures—iterative optimization of the multiloop closures to satisfy various criteria on: stability, sensitivity, performance, and workload.

Closed-Loop and Displayed Signal Properties—description of the final closed-loop system in terms of its frequency bandwidth, dominant modes, effective delays, scaling, and resolution.

System Performance—error spectra and relative contributions due to commands, disturbances, and pilot remnant.

Pilot Workload—metrics for the pilot's workload in scanning, equalizing, and optimizing the task.

Display Utilization—models and indices for the pilot's use of the display, including visual fixation traffic among key instruments, and rules and means for improving the arrangement of various displays.

CONCLUSION

A combination of multiloop analysis techniques, multiloop pilot response models, and the scanning and sampling perceptual model provide the means for the calculation of the quantities to be displayed, the pilot's behavior, system performance including the pilot's workload, and the preferred arrangement in the case of simple integrated head-up or-down displays and segregated instrument displays. For the cases of more complex integrated or panoramic visual displays, as well as for tactual, vestibular, and auditory modalities, new predictive perceptual models are required. Their formulation and verification remains for the future.

In application to design a visual display system for aircraft instrument landing approach, the theory reveals strong interactions among the numerous factors involved, such as: task performance criteria, guidance inputs, disturbances, multiloop dynamics, pilot's display scanning effects, system performance and pilot workload. The face validity of the results is strengthened by: the particular display feedbacks revealed as "best," the high scanning workload requirements, the reasonable error levels and frequency bandwidths and similarity of the derived display arrangement to airline practice.

SYMBOLS

c	Control action by the human pilot
d	Disturbances external to the human pilot
e	Error signal
f	Ocular fixation frequency
h	Altitude deviation from glideslope
i	Command input signals
m	Vehicle motions
p	Rolling component of vehicle angular velocity
q_{ij}	Ocular fixation transition probability (link value) in the direction of $i \rightarrow j$
Q	Sensory loading (non-dimensional information metric)
s	Dependent variable for the Laplace transform
T_d	Ocular fixation dwell interval
u	Longitudinal component of perturbed translational velocity of vehicle
v	Lateral component of perturbed translational velocity of vehicle
w	Normal component of perturbed translational velocity of vehicle
W_s	Scanning workload (non-dimensional cumulative fixation dwell ratio)
$\overline{x^2}$	Time variance (mean-square) of a sample function of time, $x(t)$
y	Lateral deviation from localizer
δ	Control displacement, particularized by a subscript
Δ_s	Random sampling characteristic determinant of average multiloop error
θ	Perturbed pitch attitude angle
φ	Perturbed roll attitude angle
φ_i	Estimator of the probability of the ith ocular fixation
ψ	Perturbed heading angle

Special Subscripts

a	Roll control, e.g., aileron
c	Command
e	Error; pitch control, e.g., elevator
g	Atmospheric gust, when affixed to u, v, w, p, in particular, denotes corr sponding component of air mass velocity
i	Index
j	Index
T	Throttle or thrust control

Abbreviations

AAL	American Airlines
ADI	Attitude Director Indicator
HSI	Horizontal Situation Indicator
PAA	Pan American World Airways

Mathematical Symbols

$\cdot$	(raised period) differentiation with respect to time
$\frac{z}{x}(s)$	generalized transfer function, $z(s)$ divided by $x(s)$, for the operational relationship between x and z
$\rightarrow$	fed to (in the sense of feedback control through the human pilot)

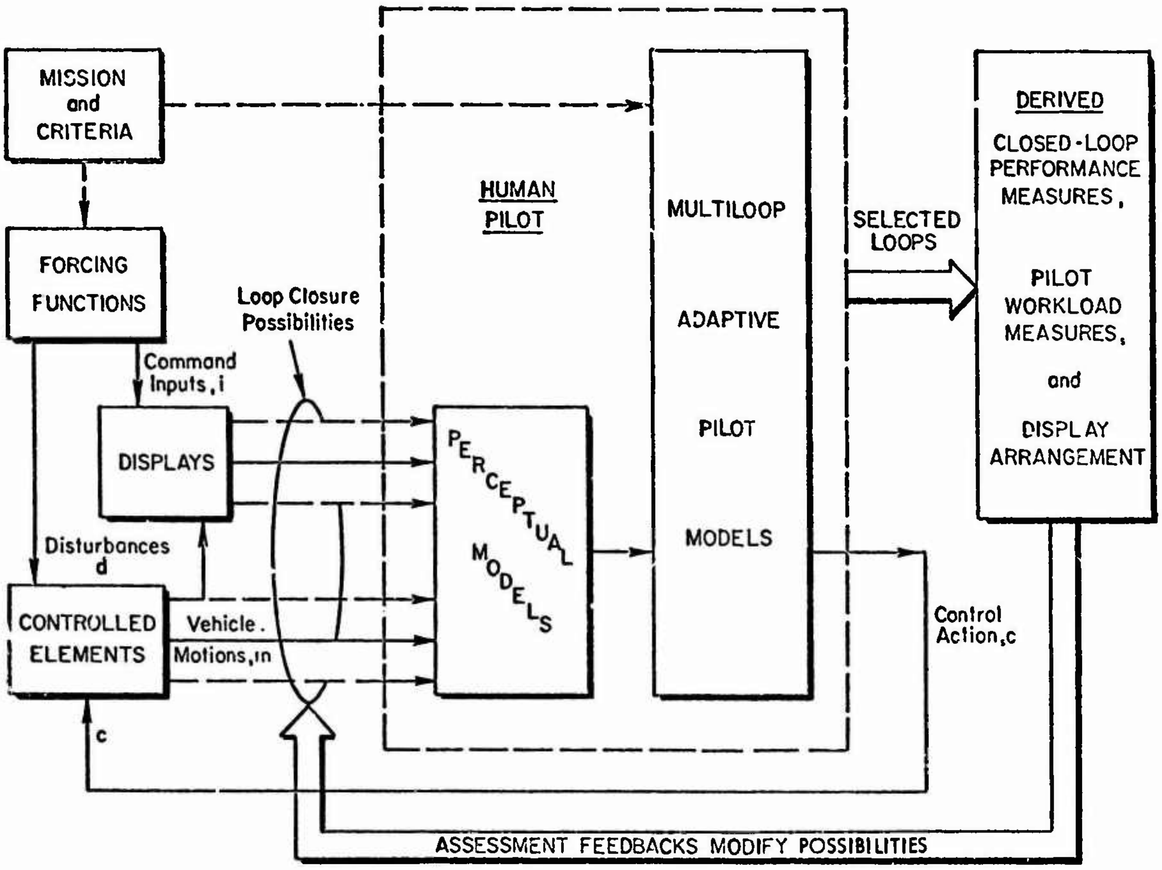

Figure 1. Scope of Manual Control Display Theory

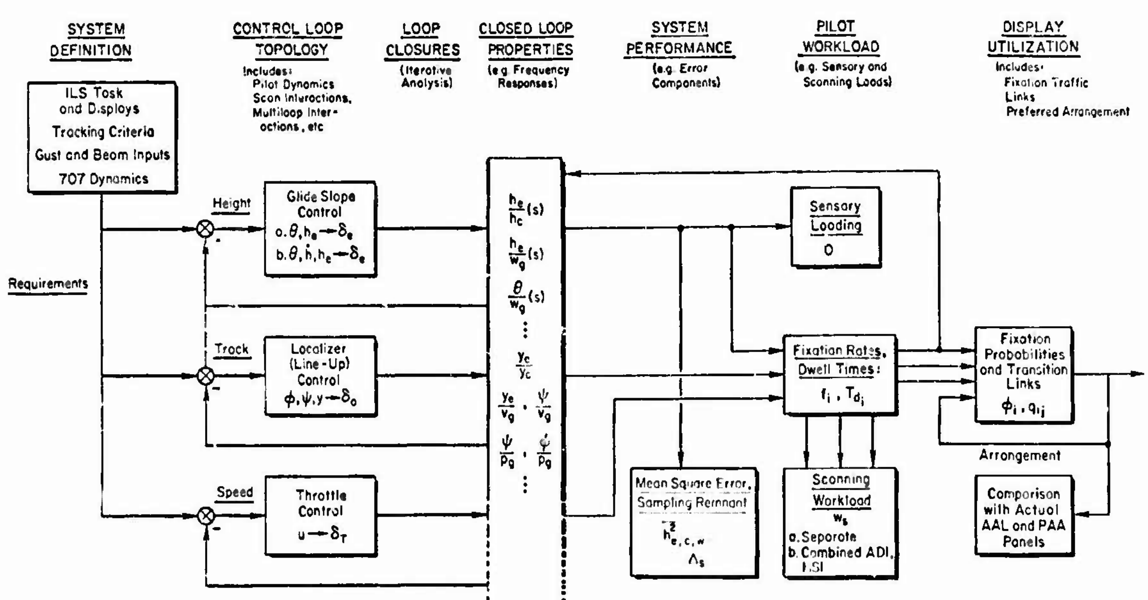

Figure 2. Flow Diagram for the Steps in the Illustrative Example of ILS Display for a Jet Transport

PROBLEMS OF INFORMATION TRANSFER IN THE MODERN JET COCKPIT

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"The problem of warning is inseparable from the problem of decision. We cannot guarantee foresight, but we can improve the chance of acting on signals in time and in a manner calculated to moderate or avert a disaster.[1]" This statement was made in reference to the critical nature of a transfer of a kind of information that is different from that being dealt with in this conference. However, the statement also seems to make sense in the context of information transfer in the jet cockpit. The goal in flight safety research, as applied to improved cockpit malfunction warning systems, seems almost to be striving to have a magician, like King Arthur's MERLIN, in the cockpit. A MERLIN in the cockpit would be ideal, since he lived backwards in time, and consequently could "remember" what was going to happen in the future.

The ideal predictor is not, of course, attainable, although attempts in this direction have been made, wherein methods of Wiener[2] are incorporated into some display applications.[3] Another form of prediction, the fast-time predictor,[4] has also been introduced into aircraft display systems. Applications of prediction concepts are limited, however, in the sense that not all events are predictable. It follows then, that if the time to act on signals is to be maximized, an objective that is assumed to be desirable, then more emphasis must be placed on improving the chances of acting quickly and properly on the signals that are available.

This paper deals with four facets of the problem of improving information transfer in the cockpit: (1) statement of and discussion of a problem area, (2) a taxonomy of flight safety research, (3) a discussion of how flight safety research might be correlated with careful regard and consideration of the above taxonomy, and (4) a discussion of steps now being taken in a planned experimental approach towards improvement of information transfer in the cockpit.

STATEMENT OF A PROBLEM

Today's highly advanced state of development of a complex technology of information processing, display systems, and control theory, seems to be not well matched to an also highly advanced state of development of high performance aircraft. This paradoxical situation might be stated in the following hypothesis:

> Gaps exist in the transfer of information to the pilot of a jet aircraft. Thus, the pilot does not have sufficient information to quickly identify certain potentially dangerous flight conditions.

Since corrective action must often be taken within seconds, delays in making decisions and delays in taking corrective actions can result in disaster. The open literature of flight safety contains many case histories of actual accidents where the pilot or pilots seemed to be faced with a lack of certain kinds of information. In such critical situations, the pilot has had to waste precious time, which might have been better used to take corrective action, for diagnosis of his situation. A small sample of some probable causes of fatal accidents of the nature being referred to above are the following: a malfunction was disguised by turbulence, and not quickly identified; a malfunctioning electric trim motor was not detected; development of excessive yaw was not detected; stall and illusion of stall have also been cited as probable causes of fatal accidents.

The above statements, indicate that some serious problems still exist in the interface between the aircraft and crew, and, when encountered, atmospheric disturbances. There is little doubt that closed files of accident investigators, which could not be utilized in this study, would add many other case histories of this nature. Thus, it seems that it is safe to conclude that information gaps do exist. A factor which may be contributing to such gaps is a lack of overall coordination of flight safety research. The implications of lack of correlation of research efforts are presented and discussed briefly in the next section.

A TAXONOMY OF FLIGHT RESEARCH

During the course of an international meeting on flight safety, held in 1967, a group of more than thirty experts, from many countries, were asked to state their views on the top priority items of flight safety research. The responses can be grouped into several categories, such as landing safety, man-machine relationships, hazards, like traffic and fire, and structures. If one now looks into flight safety projects currently under way, or recently completed, while keeping in mind the 1967 consensus of priority areas, several questions are likely to arise, such as "are the top priority problems really being worked on effectively?" On the other hand, a naive conclusion might be incorrectly reached that happily all the top priority problems are now being investigated, and consequently, that set of problems will soon be solved.

A question which should be raised in this regard is a subtle one namely, how do the various projects in flight safety, each addressed to a slightly different problem statement, and with a different combination of objectives, approaches, and end results in mind, fit into the overall problem? This question will be better understood if consideration is given to Table I, A TAXONOMY OF FLIGHT SAFETY RESEARCH, and Table II, A List of Recent Projects in Flight Safety Research. For example, consider an effort directed towards solving the man-machine, varying workload problem during takeoff, approached by way of interview of pilots, with an objective of improving information transfer, with an expected end result of go/no-go computer and

voice warning system. This same problem statement could also be coupled to other approaches, by researchers having different objectives, and also with different end results in mind.

Even if it is not realized that the lists given in Table I are not complete, and additional entries can be made in each column, it is clear that a very large number of combinations of statements of problems, approaches, objectives, and end results are possible. Furthermore, by inspecting Table II, and by scanning references of past work, it seems that most of the combinations that are possible have already occurred. Yet, the complex nature of the overall problem, coupled with a lack of coordination and/or correlation of research efforts leads to an accounting for the paradoxical situation described above, under the statement of the problem. Thus, problems that require attention still exist, even though much effort has been, or is being directed towards their solution.

CORRELATION OF EFFORT IN FLIGHT SAFETY RESEARCH

Careful consideration of the nature of flight safety research, as shown in Table I, should be given to the planning of, and conduct of, such research. By coordination of such thinking, particularly where interdisciplinary interests overlap, more effective progress is likely to be made. And, perhaps an even stronger statement can be made, namely, that significant progress is not likely unless there is more coordination and correlation among the many technical interests and disciplines of workers in flight safety research. To illustrate, an effort to study operational effectiveness of a new computer-based display concept to indicate to a pilot any significant deviations from an expected aircraft trajectory during turbulence would have to involve a rather complicated interaction among pilot, human factors, aeronautical, computer display, and meteorological personnel. It is clear that the outcome of such an effort would be strongly affected by the overall breadth of the viewpoint of the task leader of the program. With a careful overall consideration, separate, and hopefully more closely related, efforts might be realized.

A CONCEPT FOR IMPROVEMENT OF INFORMATION TRANSFER

The taxonomy of Table I resulted from extensive consideration of the evidence which supports the hypothesis that there exists a lack of information transfer. A second consequence of the pondering of this evidence was the evolutionary development of a new concept of a display. The final section of this paper presents the concept, and describes current steps being taken to refine and further develop the concept, which is stated as follows:

> The transfer of information to the pilot will be enhanced through use of a central primary flight control status and command readout. This readout would indicate status and suggested corrective action or command information, for normal or routine flight conditions, caution, or emergency situations on a priority interruption basis.

A suggested location for such a display is shown in Figure 1. The concept is based on the assumption that certain data are not always given to the pilot, even though it may be readily available inflight. The primary reason for not displaying all possible data is a lack of panel space in the cockpit. However, such a disadvantage can be offset by use of a time-shared display, wherein signals of highest priority are sequenced on the display. By placing such a display in a prime area, the pilot would have a uniform place to obtain flight information in a non-cluttered way.

The message structure is established to have a three-class hierarchy: ROUTINE or NORMAL, CAUTION, and EMERGENCY. Typical messages in each class would be: (1) ROUTINE - sequencing of check list; (2) CAUTION - low oil pressure; (3) EMERGENCY - excess yaw. Message pairs which are being considered are listed in Table III. The present study has the objective of determining the message formats, size, effectiveness of color coding and coupling of audio signals with the visual signal. Eventually, full scale simulation tests and flight tests would take place to validate the concept.

This paper is based upon research supported internally by Cornell Aeronautical Laboratory, Inc.

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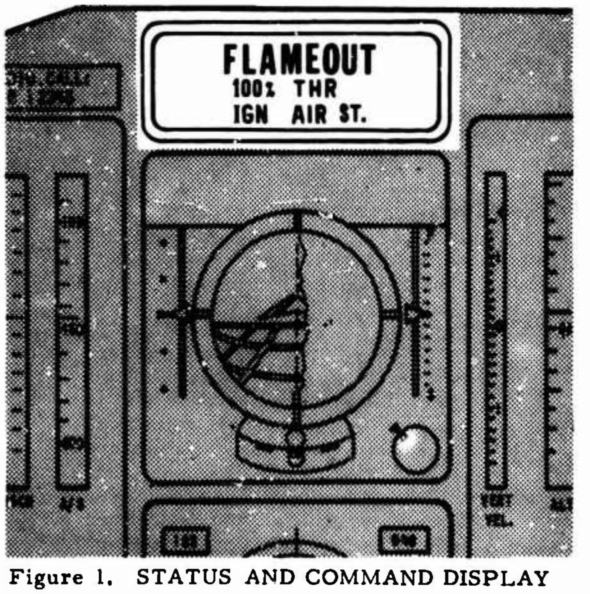

Figure 1. STATUS AND COMMAND DISPLAY

TABLE I A TAXONOMY OF FLIGHT SAFETY RESEARCH

PROBLEM STATEMENTS

- MAN-MACHINE RELATIONSHIPS
  - VARYING WORKLOAD
  - CONTROL IN TURBULENCE
  - STALL, AT HIGH SPEED
  - STALL, AT LOW SPEED
  - INTERPRETING INSTRUMENTS IN TURBULENCE
  - FATIGUE, VIGILANCE PROBLEMS
  - MUTUAL UNDERSTANDING OF RESPONSIBILITIES
  - DESIGN-INDUCED PILOT ERROR
  - SYSTEM GOOFS
- DISPLAY FAILURES
  - SITUATIONS PILOT IS NOT AWARE OF
  - INATTENTION
  - FALSE ACCELERATION CUES IN THE COCKPIT
- SITUATIONS PILOT IS AWARE OF, BUT NEEDS HELP
  - POOR INSTRUMENT RESPONSE
  - LOSS OF WARNING INDICATORS
- STRUCTURAL INTEGRITY
- FIRE SAFETY
- GENERAL WARNING FOR MALFUNCTION EMERGENCIES
- TAKEOFF PROBLEMS
  - GO - NO - GO DECISION BASIS
  - CONTROL AT ROTATION
  - MALFUNCTIONS DURING TAKE - OFF
  - NOISE ABATEMENT CONTROL
- CLIMB-OUT
- CRUISE
  - UPSET
  - UNSTART
  - LOSS OF CONTROL DUE TO SPEED CHANGE
- ROUGH AIR - UPSET PROBLEM
- DESCENT
- COLLISION AVOIDANCE
- LANDING
  - SAFETY IN APPROACH AND LANDING
  - ALL-WEATHER LANDING
  - CONTROL AT LANDING SPEEDS
  - GLIDE PATH CONTROL
  - TOUCHDOWN IN CROSSWIND
  - WHAT ARE THE LANDING CUES?
  - USE OF ANGLE OF ATTACK DURING DESCENT
  - RECOVERY LAG DURING DESCENT
- TERRAIN AVOIDANCE
- INTERNATIONAL STANDARDS FOR SAFETY
- C.A.T.
- IMPROVED FLIGHT RECORDERS

APPROACHES TO SOLUTIONS

- ANALYSIS AND STUDY OF ACCIDENTS
- STUDY A SPECIFIC FLIGHT MODE
- NEW SENSOR DEVELOPMENT
- DEVELOP INERTIAL INSTRUMENTATION
- EXPERIMENTS ON SIMULATORS
  - SIMPLE LABORATORY SIMULATORS
  - STUDIES USING FULL-SCALE SIMULATORS OF AIR FORCE
  - STUDIES USING FULL-SCALE SIMULATORS OF INDUSTRY
  - STUDIES USING CENTRIFUGE SIMULATOR
  - STUDIES USING SIMULATORS OF AIRLINES
- EXPERIMENTS IN AIRCRAFT
- EXPERIMENTS IN VARIABLE STABILITY AIRCRAFT
- USE OF TOTAL IN-FLIGHT SIMULATORS
- STUDY TURBULENCE EFFECTS ON CREW
- DEVELOP NEW DISPLAY CONCEPTS
  - CRT DISPLAYS
  - MALFUNCTION DISPLAYS
  - FULL USE OF AUDIO DISPLAY
  - PREDICTOR DISPLAY
  - CORRECTIVE ACTION DISPLAY
- TOTAL REVOLUTION IN COCKPIT INSTRUMENTS
- STUDY COMPUTER APPLICATIONS
  - PREDICTOR/MONITOR
  - GO-NO-GO STUDIES
  - P.I.O. PREDICTOR
- HUMAN FACTORS STUDIES
  - STUDY TRAINING METHODS
  - CONDUCT INTERVIEWS
  - ANALYSIS OF WORKLOAD
  - PILOT REACTION STUDIES
  - DISORIENTATION EXPERIMENTATION
  - HUMAN FACTORS IN AIRCRAFT ACCIDENTS
  - TRANSFER FROM TRAINING
  - TRANSFER FROM PISTON EXPERIENCE
  - TRANSFER FROM MILITARY TO CIVILIAN
- EVALUATION OF DISPLAYS
  - HEAD-UP VS. HEAD-DOWN
  - COMMAND VS. SITUATION
  - INSIDE-OUT VS. OUTSIDE-IN
  - EVALUATION STUDIES OF EXISTING AND PROPOSED DISPLAYS
  - INTEGRATED DISPLAYS
  - USE OF ANGLE OF ATTACK INDICATOR
  - USE OF g METERS
  - USE OF TAPE DISPLAYS

RESEARCH OBJECTIVES

- DEVELOP DEVICES
- EVALUATE CONCEPTS
- DISPLAY EVALUATION PROCEDURE
- CONSIDER PILOT'S VIEWPOINT
- IMPROVE INFORMATION TRANSFER

END RESULTS

- REPORTS
- FIXES OF EXISTING DISPLAYS
- ANGLE OF ATTACK DEVICE
- IMPROVED VOICE WARNINGS
- NEW HEAD-UP DISPLAY WITH CORRECTIVE ACTION DISPLAY
- FLYING TRAINER/LABORATORY (TIFS)
- PIPE DREAMS
- GUST SENSOR AND DISPLAY
- GO-NO-GO COMPUTER
- P.I.O. PREDICTOR
- INERTIAL INSTRUMENTATION
- PREDICTOR COMPUTER
- TOTALLY NEW COCKPIT
- THEORY OF DISPLAY EVALUATION
- IMPROVED WARNING SYSTEM AND DISPLAY
- CHANGES IN TRAINING PROCEDURES

TABLE II RECENT PROJECTS IN FLIGHT SAFETY RESEARCH

COCKPIT LAYOUT	DEVICES AND SYSTEMS
• COCKPIT LAYOUT AND INSTRUMENT PRESENTATION • COCKPIT VISUAL DISPLAYS • VISUAL INTEGRATED COCKPIT PRESENTATION • COCKPIT LIGHTING STUDY • COCKPIT LAYOUTS & PROCEDURES • THE "UNIFIED" COCKPIT • INSTRUMENT DISPLAYS	• TACTILE STALL-WARNING DEVICE • TACTILE COMMUNICATION SYSTEM • DESIGN INDUCED PILOT ERROR • TAKE-OFF DIRECTOR • AIRCRAFT PERFORMANCE MEASUREMENTS • CONTROL SYSTEM ANALYSIS • TAKE-OFF MONITORING • TAKE-OFF MONITORING SYSTEMS
HUMAN FACTORS	**LANDING STUDIES**
• HUMAN FACTORS IN AIRCRAFT ACCIDENTS • HUMAN FACTORS IN CAUSE-UNDETERMINED ACCIDENTS • DISORIENTATION IN FLIGHT • JET PILOT-AIRCRAFT COMPATIBILITY • PSYCHOLOGICAL FACTORS OF FLIGHT CONTROL • PILOT'S WORK LOAD IN A CIVIL AIRLINE • TRAINERS AND TRAINING PROGRAMS • JET CREW FATIGUE • HUMAN FACTORS IN THE DESIGN OF CONSOLES	• LANDING CONTACT CONDITIONS • PROBLEM OF AUTOMATIC BLIND LANDINGS • ALL-WEATHER APPROACH AND LANDING SYSTEMS • LANDING DISPLAY VIA MICROWAVE • AUTOMATIC LANDING SYSTEMS - CIVIL USE • GUST EFFECTS IN APPROACH & LANDING • AUTOMATIC LANDING EQUIPMENT
INSTRUMENTS	**WINDSHIELD DISPLAYS**
• DIRECT READING THRUST METER • ANGLE OF ATTACK INSTRUMENTATION • ALTITUDE MEASURING SYSTEMS • ALTIMETER DISPLAY RESEARCH • AIRCRAFT INSTRUMENTS • PREDICTION DISPLAY FOR ATC • QUICKENED VISUAL GUIDANCE	• PROJECTED WINDSHIELD DISPLAY • PROJECTED SYMBOLIC DISPLAY FOR GENERAL AIRCRAFT • PROJECTED SYMBOLIC DISPLAY FOR TRANSPORTS

TABLE III MESSAGE PAIRS FOR COCKPIT DISPLAY

NORMAL SITUATIONS	CAUTION SITUATIONS	EMERGENCY SITUATIONS
CHECK LIST ITEMS EST. WT. REF. SPEED CHECK & SET GO-AROUND EPR CHECK & SET SHOULDER HARNESS ON YAW DAMPER SW. ON ENGINE ST. SW. ON LANDING GEAR DOWN BRAKES OFF AUTOPILOT OFF	AIL. PCU LOW PRESS. SEC. PCU STDBY FUEL BOOST PUMP MONITOR PRESS. HIGH CABIN PRESS. CK LANDING GEAR NOT UP RETRACT FLT. DIR. GYRO FAIL SW. GYRO CALL FAA CTR DCA 125.2 RADIO FAILURE VHF	MIDAIR DIVE FLAMEOUT 100% THR. IGN AIR ST. ENGINE FAIL # 2 THR. CLOSE FLT. IDL, ST. LVR OFF IGN CONT. ELEC. PWR. CK PRESS. CK EXCESS VERT. SP. ADJ. VERT. SP. EXCESS YAW RUDDER CONTROL

Some Thoughts on V/STOL Dieplays and Approach Tochniquee

by

Sqn. Ldr. R.W. Millward

1. INTRODUCTION

While there may eventually be a need to develop an IFR V/STOL technique for zero/zero conditions, and hence for display layouts to permit such all-weather operations, it appears only neceesary at thie stage to aim for operating minima similar to those of conventional aircraft in the same role.

The task is therefore to bring a V/STOL aircraft from a conventional (i.e. fully wing-borne) flight regime in the vicinity of a landing eite to a position from which the pilot can make a visual vertical or short landing.

2. CONSIDERATION OF THE TASK

The achievement of this task is primarily influenced by the weather minima selected by the operators, and two extreme viewpoints may be postulated:

1. There is a need to develop an IFR V/STOL technique enabling the pilot to operate virtually in zero/zero conditione;

or 2. Current operational minima of, say, 200 ft and ½ N.M. should be considered as a reasonable aiming point for V/STOL inetrument approaches.

In considering these two extremes, it ie relevant to observe that the ability of a pilot to carry out an IFR approach in zero/zero conditions ie sufficiently in doubt to have led to the development of multiplex autoland systems. The writer euggeets that similar developments may aleo be eesential for V/STOL operations in zero/zero conditions. Two advantagee offered by V/STOL aircraft may poeeibly invalidate thie extrapolation. These are:

1. The ability to oarry out the last segment of the approach at very low speed, thus increasing the reaction time available to the pilot.
2. The ability to apply direct lift and drag control to the aircraft at constant attitude.

While not diecounting the eventual feasibility of V/STOL operations in zero/zero conditions, these advantages should enable us to operate high-performance aircraft in approach conditions appropriate to a slow communications airoraft. Thus, the conditions in which a pilot would be prepared to operate a light airoraft or a helicopter are probably suitable for V/STOL operations at, eay, 50-70 kts. If we can, then, make the handling task and the instrument flying workload similar to that of a slow conventional aircraft, we will have achieved an adequate etandard for the task.

The following comments are therefore directed mainly at the need to achieve operating minima of 200 feet and ½ M.N. for a visual vertical or short landing.

3. THE PILOTS' REQUIREMENTS

3.1 Situation Information. The pilot requires certain basic information to enable him to adjust or hold any eelected flight path. This ie normally presented to him as height, speed. vertical epeed, heading and ground position (or position relative to a ground reference). In addition, he may require indication of incidence, sideslip, track and glidepath errore or flight path vector to enable him either to avoid "corners" of the handling envelope or to minimise his flight path deviations. This eituation information must be of a sufficiently high quality to indicate "tendenciee" and rates.

3.2 Stability and Control. The pilot's ability to carry out adjustments to a flight path or to make good a ground track is significantly improved if he does not have to devote large amounte of attention to retaining physical control of the aircraft. Some current V/STOL aircraft poseess certain unpleasant basic handling features such as low (or negative) directional stability, strong rolling moments with sideslip etc., which make undue demands on the pilots' attention. The solution lies either in good natural handling qualities or an optimised autostabiliser, the latter preferably in attitude.

3.3 Guidance. There seems little need for additional guidance information in the form of flight directore if the situation information is of the same quality as that presented by the real world. Directors demand a high degree of concentration, partly because they are compelling, but even more because, if the pilot "loses" the director, he usually has insufficient situation information to enable him to retrieve the aircraft normally. The writer strongly believes that only adequate situation information will give the pilot the required level of confidence in a multiple director task, and, if this information is available, then tight director guidance is probably unnecessary. In the case of the V/STOL aircraft, there ie no need to constrain the pilot to follow a particular approach path to the landing point, and the selection of a ground track is dictated solely by the needs to avoid obstacles and to arrive at the landing point at zero or very low speed. Tight constraint to an ILS - type glidepath and track is therefore unnecessary, and full use should be made of this freedom and potential.

3.4 Technique. Pilot techniques in instrument flight have always been based on a "do-one-thing-at-a-time" - principle. This is a natural human response to a demanding set of tasks, and the V/STOL aircraft does not offer the possibility of a more relaxed approach. The

writer favours the "stepped approach" technique, the essence of which is to separate the approach and landing pattern into phases which are completed in turn, each involving changing only one quantity at a time. An initial deceleration from conventional speed to, say, 70 kt is made at a roughly constant safe altitude and followed by a descent at constant speed until either the minimum break-off height is reached or the pilot has seen the ground (not necessarily the landing area). At this point, the flight path is adjusted, and the aircraft continues towards the landing area, to complete the landing (slow or vertical). In contrast with the landing of a conventional aircraft in which airspeed, height, flight path and position relative to the runway all have to be correct simultaneously at a "gate" at the end of the approach, the recommended V/STOL technique is much more flexible, giving the V/STOL aircraft its potential advantage.

4. DISPLAY

The pilots' needs can be divided into two forms of information:-

4.1 Situation. The pilot needs to know, at any time, his attitude, his position in space and his tendency. For this, he requires high quality situation information, as already discussed, and this should include plan-position information. In order to complete his knowledge, rates of change of information are as important as "raw" numbers, but the head-up display, though attractive at first sight, very quickly becomes cluttered to the point of confusion if all the required information is included. The writer favours high quality head-down information and a clear windscreen.

4.2 Directors. It is recognised that a tighter control of flightpath can be achieved with directors, but this becomes less necessary as approach speeds are reduced. Moreover, their use generally results in a reduction in the pilot's capacity to monitor other vital information (fuel, engine parameters, radio etc), and few pilots can satisfy more than two directors at a time and retain any spare capacity. With normal transport-type operations, the use of two pilots permits "split" duties, with one pilot cross-checking situation information, but we must also cater for the military single pilot role. Thus, the writer believes it would be better to optimise the situation display, even if this entailed deletion of directors, for single-pilot operation.

5. V/STOL OPERATING PROCEDURES AND APPROACH AIDS

Recent jet V/STOL, helicopter and simulator experience at R.A.E. has suggested possible approach and landing procedures using the "stepped approach" technique. With only a homer beacon, a timed pattern starting from an "on top" fix would put the aircraft into position for the descent and final deceleration to the landing. Inertial navigation, by relieving the pilot of the task of timing the pattern would make the pattern more precise while Tacan, with its range and bearing information, could obviate the pattern altogether.

Although possible for a single pilot, these procedures are much better suited to two pilot operation, partioularly in the case of transport aircraft, where one pilot is able to concentrate on navigation and pattern procedures while the other maintains complete command of the aircraft and its systems. This proved to be a practical solution to a complicated approach task on a flight simulator without directors, but using a normal situation display augmented by a plan position indicator.

US experience (see "Vertical World", August 1967) of tactical helicopter operations using a portable ADF beacon supports this view, recognising the advantage of two pilot operation and stressing the importance of avoiding changing speed during manoeuvres.

6. CONCLUSIONS

It is concluded that, for V/STOL approach tasks in IFR conditions:-

1. Operational minima of 200 ft and ½ N.M. should be aimed for.
2. High quality situation information is required, including plan position information relative to the landing site.
3. Director displays may be redundant when adequate situation information is provided.
4. The "stepped" approach offers the best level of pilot confidence and performance.
5. Stability and control characteristics of V/STOL aircraft should be as good as those of conventional low speed aircraft: if necessary, attitude autostabilisation should be used to produce the required handling characteristics.

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INVESTIGATIONS OF THE TERM "REMNANT SPECTRUM" OF THE HUMAN CONTROL OUTPUT FUNCTION

1. General

The known models for describing man's performance as a link in a control system are primarily based on a linear transfer function. These models cannot serve entirely to describe man's dynamic performance. Since the days of the investigations by CRAIK(1), we know that man performs a dynamic control task, e.g. a tracking task, with intermittent sensomotoric control inputs. The result is that man's input spectrum in a given task shows also frequencies which are not part of the input forcing function.

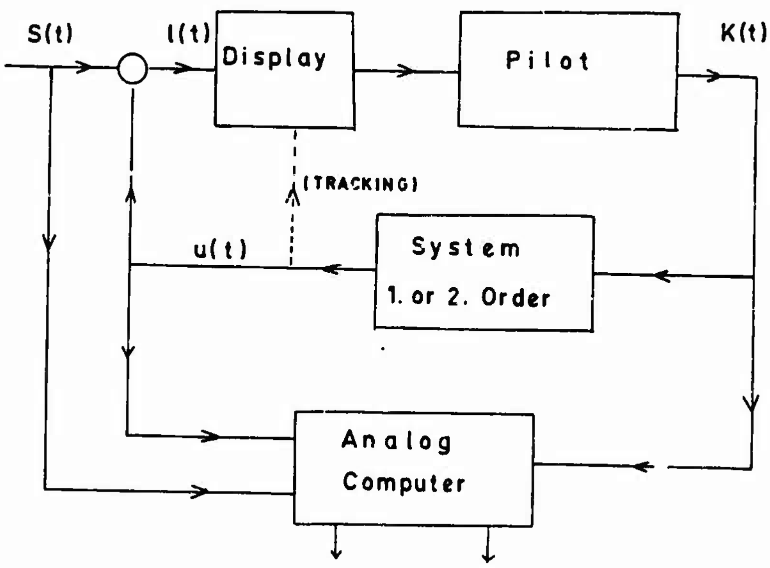
One possibility is to define this "over-control" of man as "pilot-noise" and look at it as an additional stochastic interference. This improves the linear approach considerably, as in the work by SCHWEITZER(2). But such a model can also only be applied to predict man's performance in a very restricted range of system characteristics.

The goal of our investigations is to find criteria to assess man's performance in a given system and - on the other hand - to find methods to define the task load, and therewith the difficulty of a system, without applying known descriptive models.

The rationale of our approach is to investigate manual tracking control systems, while applying mathematically defined varied input forcing functions. - You can easily imagine that the systematical variation of the input spectrum assumes that one is willing and able to perform a great number of single experiments, always using a group of subjects and cutting out the transfer effect as far as possible. At this point we are still at the beginning of the entire investigation and only a survey of the experimental approach can be given.

2. Experimental Arrangement

As yet two systems have been investigated - a first order and a second order system - with a transfer function of $\frac{1}{s}$ and $\frac{1}{s^2}$. Also two tasks were performed, a compensatory and a non-compensatory - or pursuit - tracking task.



$$F = \int[e(t)]^2 dt \qquad L = \int[\dot{K}(t)]^2 dt$$

where:
- S(t) = forcing function (disturbance)
- K(t) = stick movements (human output)
- u(t) = system response (system output)
- e(t) = S(t)-u(t) = error

The tracking time per run was T = 4 min.

2.1. Measured Criteria

a) The output error:

$$F = \frac{1}{T}\int_0^T [e(t)]^2\,dt = \frac{1}{T}\int_0^T [S(t)-u(t)]^2\,dt$$

$$= \overline{e^2(t)} = \text{mean square error and}$$

$$\sqrt{\overline{e^2(t)}} = \text{root mean square error}$$

b) The stick movement (performance activity)

$$L = \frac{1}{T}\int_0^T [\dot{K}(t)]^2\,dt = \text{mean square stick velocity}$$

$$\sqrt{L} = \sqrt{[\dot{K}(t)]^2} = \overline{\overline{\dot{K}(t)}} = \text{root mean square stick velocity}$$

2.2. Display Data

A two-channel CRT of 12cm Ø was applied, with a beam deflection of 1 V/cm. With the compensatory task being only e(t), the error was displayed together with a fixed reference line. With the pursuit display the forcing function S(t) and the system response u(t) was displayed.

2.3. Stick Characteristics

Maximum movement: ± 13cm ≙ $\pm 14^\circ$ ≙ ± 9 Volts
This means:
For rate control (1st order system) a maximum stick signal velocity of 9 Volts/sec., i.e. 9cm/sec. on the display; and for acceleration control (2nd order system) a maximum stick signal acceleration of ± 18 Volts/sec^2, or 18cm/sec^2 on the display.

2.4. Forcing Function Data

All these mathematical data are necessary to define the degree by which the forcing function can be controlled by the human controller.

The spectrum consists of 4 frequencies. The amplitude or power distribution has been varied to an extent that for both systems (1st and 2nd order) a similar stick-movement-performance was necessary to entirely compensate the input spectrum.

Tab. 1: Spectrum

Frequency $[sec^{-1}]$	0,094	0,128	0,180	0,427
Amplitude [Volts] 1st order system	2,55	2,02	1,75	0,62
Amplitude [Volts] 2nd order system	3,10	1,95	1,32	0,22

The root mean square value of the amplitude $\left(\sqrt{[S(t)]^2}\right)$ was:

for the 1st order system: 2,65 Vrms
for the 2nd order system: 2,76 Vrms

The minimum necessary stick movement performance for continuous tracking - impossible for man! - was:

for the 1st order system: $L_o = 14\left[\frac{Volts}{sec}\right]^2 = 30\ \frac{cm^2}{sec^2}$

for the 2nd order system: $L_o = 12\left[\frac{Volts}{sec}\right]^2 = 25\ \frac{cm^2}{sec^2}$

3. The Sample

3.1. First order system: 6 non-pilots
6 pilots (300 - 1000 hrs. experience)

3.2. Second order system: 6 pilots (1000 hrs. experience)

4. Results

4.1. Results with the first order system

The non-pilot group had considerably more test runs than the pilot group. The non-pilot group was after about 20 runs fully adapted. The last 10 runs were evaluated.

Tab. 2: Results with the first order system

	P = Pursuit C = Compens.	Pilots	Non-Pilots	Extr. values obs. Pilots	N.-Pil.	
Mean square Error	P.- Track. C.- Track.	0,390 0,390	0,465 0,325	minimum 0,28 maximum 0,52	0,18 0,65	$Volts^2$
Root Mean Sq. Error	P.- Track. C.- Track.	0,62 0,62	0,68 0,57			Volts r.m.s. (cm on display)
%-reduct. of input power	P.- Track. C.- Track.	77 77	74 79			
Mean stick perform-ance	P.- Track. C.- Track.	46 46	56 60	minimum 15 maximum 96	43 72	$\frac{Volt^2}{sec^2}$

The pilots show a mean stick performance which is 3.3 times that of the theoretical minimum of that value necessary to reduce the input power by 100% (instead of 77%). The non-pilots 4.0 times. This applies only for the given frequency spectrum. The value of 60 $(\frac{volts}{sec})^2$ for the stick performance is equal to a stick movement range of 7 meters per minute.

4.2. Results with the second order system

Tab. 3: Results with the 2nd order system (pilot group only)

		Pilots	extreme val. obs.	
Mean square Error	P.- Track. C.- Track.	0,62 0,50	min. 0,40 max. 1,10	$Volts^2$
Root mean Sq. error	P.- Track. C.- Track.	0,79 0,71		Volts r.m.s.
% reduction of input power	P.- Track. C.- Track.	71 74		
Mean stick performance	P.- Track. C.- Track.	45 85	min. 20 max. 260!	$\frac{Volts^2}{sec^2}$

In this experiment the control gain of the stick was two times that of the experiments with the first order system. With the same stick gain as in the first order system, the results would have been considerably worse. Calculated for normal stick gain (as applied in the first order system experiments) the stick performance would amount to 16 or 30 times, respectively, of the theoretical minimum to reduce the input excitation power to zero. But such a high stick performance seems to be unrealistic.

5. Conclusions

5.1. Conclusions concerning the 1st order system experiments

All subjects show a certain amount of performance variation over the test runs. But error and stick performance vary in such a way that their product is kept nearly constant. This product, therefore, serves as a good means to assess the adaptation level of a subject.

The change of the input power $\overline{S^2(t)}$ of the excitation spectrum - frequency band kept constant - is followed by a nearly linear change of the values, error and stick performance.

Doubling the stick control gain results soon in equal performance values, as before, if the relative weight of stick velocity in the process of integration is also doubled.

The effect of changing the frequency band has not yet been investigated. It is assumed that the task difficulty increases with the frequencies applied in the forcing function band.

5.2. Conclusions concerning the 2nd order system experiments

The linear change of error and stick performance value, with respect to a change of the input power, does not apply here.

Stick performance varies extremely more than mean square error, as the extreme values observed show in Tab. 3. (Standard deviations were not calculated).

Assumption: Higher stick performance does not result in lower error but in additional disturbance of the system. This conclusion favours SCHWEITZER's descriptive model.

Stick performance values show that pursuit tracking with acceleration control seems to be easier than compensatory tracking.

Without application of an external disturbance (forcing function) pilots showed "PIO's" (pilot induced oscillations) in a frequency band of 0.1 to 0.8 cycles per second.

There is no correlation between simple reaction time and tracking performance.

6. Outlook

The result of changing the power of the exciting function in a 2nd order system needs further investigation.

The result of changing the frequency band of the exciting function shall be investigated.

Additional systems, as $\frac{1}{S(S+1)}$ and $\frac{1}{1+as+bs^2}$ shall be investigated.

These variations in system, input power, and frequency band shall be applied to a two-dimensional control system.

This outlook may show that there is still a long way to go until a systematic mathematical comparison of systems and their dependence from input variations can be made.

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INFORMATION TRANSMISSION AS A CRITERION TO EVALUATE DISPLAY SYSTEMS

by

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To be published later

Test Results with New Analog Displays for All-Weather Landings

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Summary

Two situation analog displays were evaluated on a fixed base simulator, programmed for a small propeller aircraft and a jetfighter and compared with common versions of the ILS-information.
The results exhibited small errors in approach path tracking and flare control. Allthough of the pure situation type the displays allowed easy control and high success rates.

1. Introduction

Remarkable efforts are undertaken in some countries in order to solve the problem of aircraft landing under all-weather conditions.
The system philosophies presently dominating intend to use the autopilot as the primary control component and to restrict the roll of the human pilot to a monitor. The arguments for these solutions are the higher accuracy and reliability of automatic systems. This, indeed, cannot be neglected.
However, the development and use of equipment for fully automatic landings will not reduce the need for more suitable information display. The human pilot will have to monitor the safe operation of the autopilot and should still be able to take over and complete the landing safely. This should be possible in spite of the probably lower training level, reduced by the extended automatic operation.
Furthermore there exists a large number of aircraft operators, who might be interested in the ability for complete zero-zero landing but might be unable to accept the weight- and cost-penalty of the automatic equipment required.

The question is, how the information is to be presented.
Some modern flight director systems prescribe a computed command signal the pilot has to follow in order to fly a near optimum approach path. Other, advanced display concepts offer an image of the runway and, sometimes, a "highway" leading to it, combined with additional means like scales and pointers, markers for aiming points and for the flight path, and like directors or preview aids.

In this paper it is studied how well the human pilot is able to control the complete landing with the aid of pure situation analog displays which already include all the quantitative information required.
The well known inherent limitations of the human pilot and his abilities as well have to be taken into account when designing a display system.

We intended to meet the following principles:
- transition from one field and type of info to another should be avoided,
- the pilot should not be forced to scan a number of info sources,
- the info should be presented in a habitual analog form and
- the primary function of the info should be a presentation of the situation.

2. Tracking tasks

Car driving

A great part of the worlds population is very able to maintain a vehicle on a straight or curved path.
Obviously the excellent information "display" through the windshield of a car is not the sole reason, that car driving is felt to be easy. There are only 2 degrees of freedom and the characteristics of the car dynamics are favourable compared to those of a landing aircraft. But one reason for the relative ease of car control might be, that a cardriver is well trained in precision tracking because a uniform and high accuracy is required all the time. On the contrary, a pilot is forced to control the path with equivalent precision during the short time of flare and ground roll only.

Formation flight

There have been many opportunities to admire the barrel rolls of the "diamond sixteen" or other formation acrobatics at airshows.
During all these maneuvres the pilot will continuously check and correct the smallest deviation of his aircraft in relation to the "very near by" leader. He is not forced

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to and will not be able - due to the dangers of collision - to observe his other "conventional" information sources, the instruments.

3. The New Displays

In the program reported in this paper, we tried to activate the advantages of the abovementioned tracking tasks for the landing guidance.

Display B (Boulevard)

In this case it is tried to improve the visual contact landing info - which is similar to the car driving info - by consequent application of the runway image for the lateral as well as vertical guidance during landing and approach (Fig. 1a). Due to limitations in time and equipment we were only able to realize it in a simplified form (Fig. 1b during approach; Fig. 1c during flare phase).

Display F (Formation)

The image of a leading aircraft in trailformation was substituted by a suitable symbol (Fig. 2a-d). This symbol precedes the actually landing aircraft with a fixed distance along the ideal glidepath straight down to the glidepath/runway intersection. At this moment it tips up from the approach attitude to the horizontal and continues to "roll" along the runway - centerline.
Lateral and vertical deviations from the prescribed flight path of the leading aircraft are indicated according to the perspective and geometric rules. Changes in attitude, heading and bank cause vertical, lateral and rotational motions of the entire symbol.

4. Equipment

The fixed base simulator consisted of two Analog Computers (EAI TR48, one with Hybrid components) and a cut off cockpit of a CM 170.
The characteristics of two aircraft, a single engine small propeller aircraft (B) and a jetfighter "of the 50's" (A) were programmed.
The airspeed info was displayed by the normal ASI only. Since the approach speeds were well "on the frontside of the power curve", speed monitoring was not required. For further tests speed indication in the headup field is intended.
Gusts and crosswinds of different intensity were simulated.

5. Testpersonnel

Three pilots had been available for the systematic test runs while some others participated only in a few intermediate runs.

6. Test results and Discussion

The landing approaches were started from different lateral and vertical offsets from initial distances between 4 and 6 miles. The test runs had to be stopped with touch down due to equipment limitations.
Figs. 3a, b show series of tests plotted on the same coordinate system, flown with displays B and F. Civil tolerances are included in the graphs which provide some impression about the meaning of the results in practical terms.
Control techniques, like rudder/aileron coordination, pulse type and dither technique improved the results remarkably. In crosswind conditions decrab maneuvers were made successfully.
A selection of the test results obtained with the different combinations of displays, aircraft, pilots and disturbances are shown and compared in the complete paper.
The design of the new displays is such that they inherently provide some sort of director characteristics. The pilot only has to follow simple rules when intercepting and tracking and during the flare phase. However, it is up to his decision up to which extent he wants to use the director effect in his control strategy.

7. Conclusions

After a reasonable training period the pilots were able to keep the tracking errors as well as the touch down (sinkrates and dispersions) within the limits of official standards for all-weather landings.
The mental effort required to fly display B or F was felt to be quite low. We believe, that this is caused by the uniform info-presentation in habitual analog form and by the inherent director characteristics.
The refinement and realization of the displays B and F for a flight test phase seem to be possible by application of existing guidance systems and hardware.

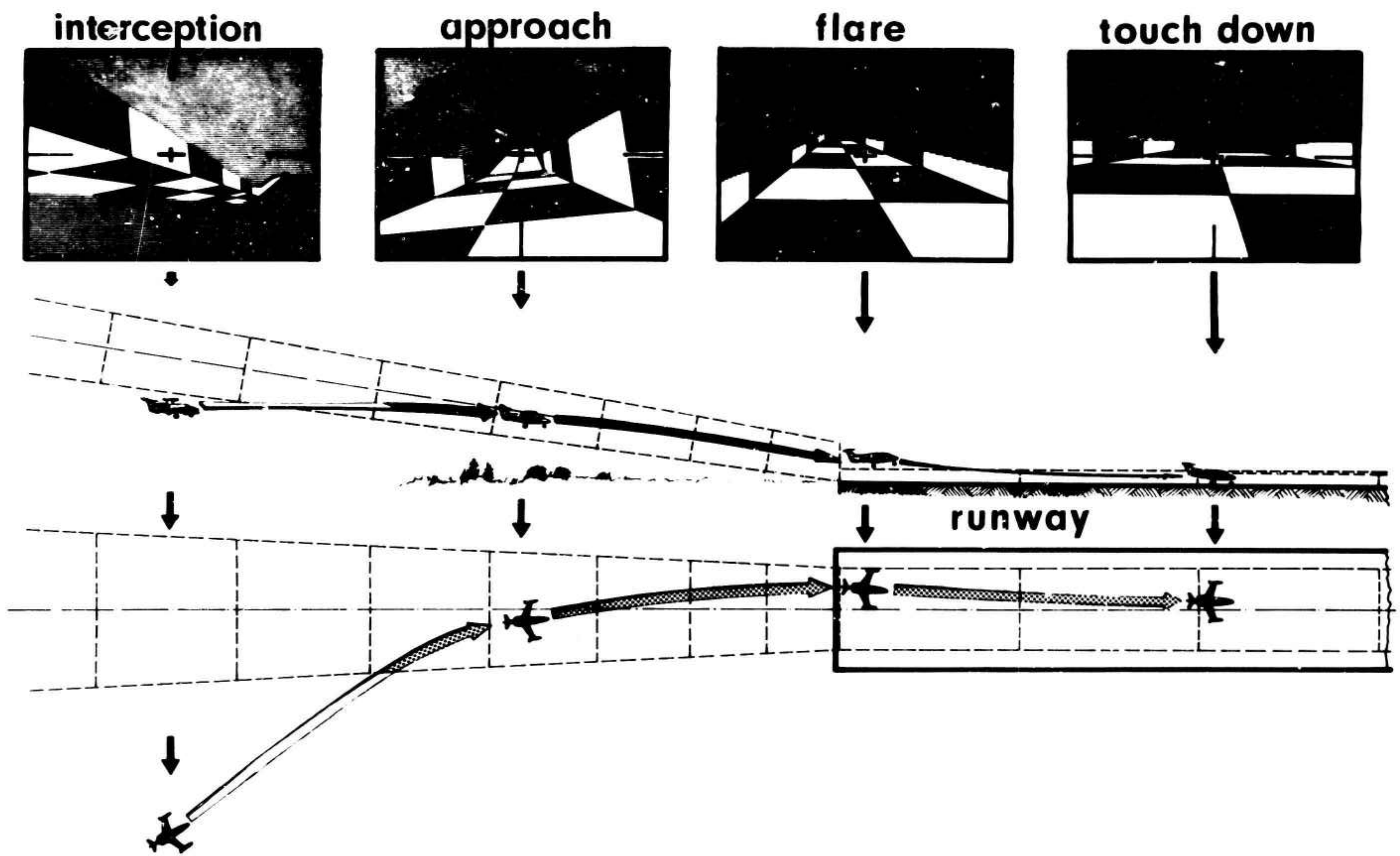

Fig. 1a: Approach + landing with display B

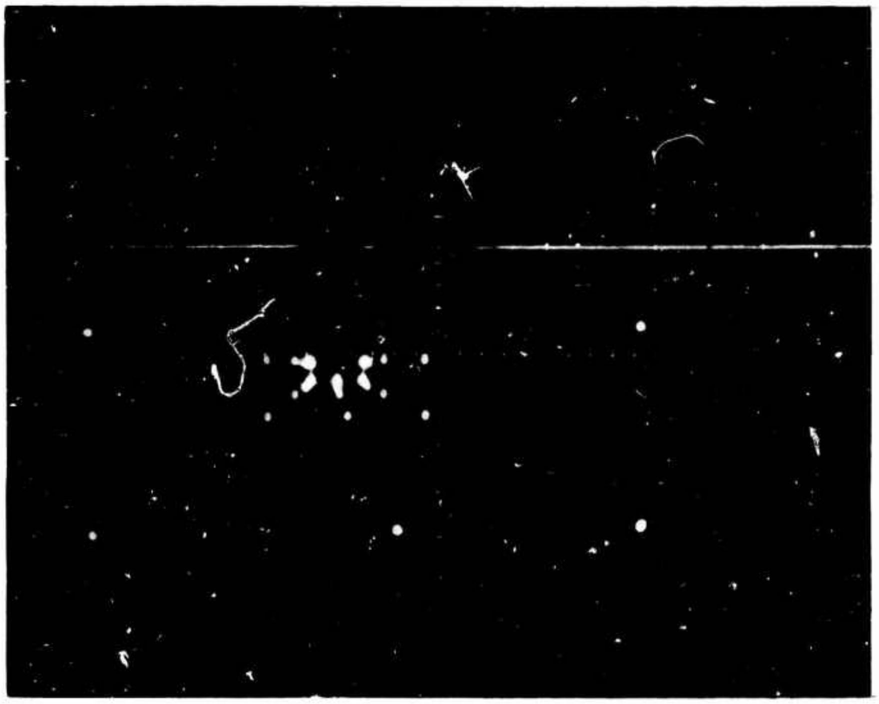

Fig. 1b: Realization of display B, approach phase

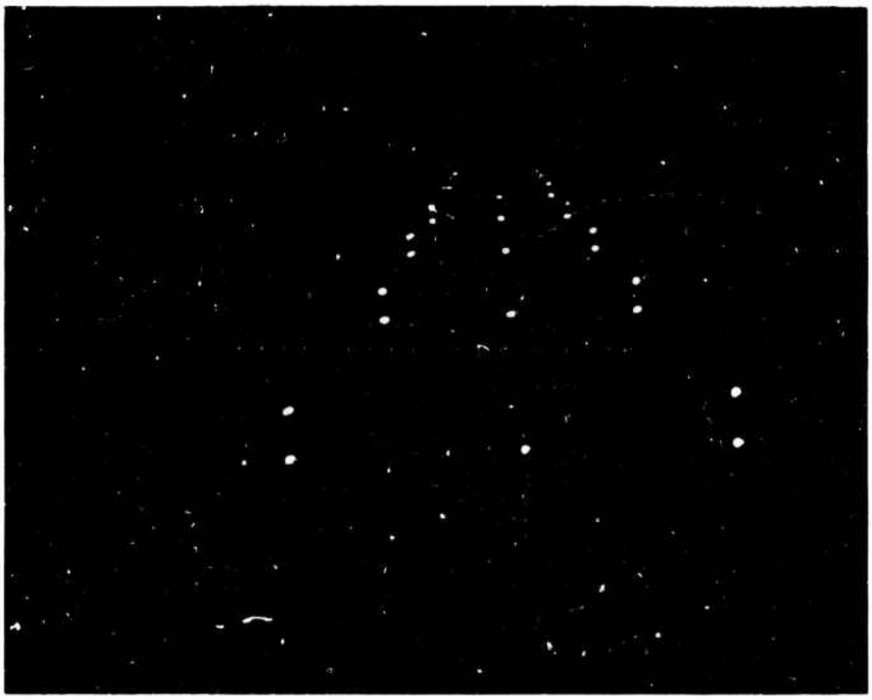

Fig. 1c: Realization of display B, flare phase

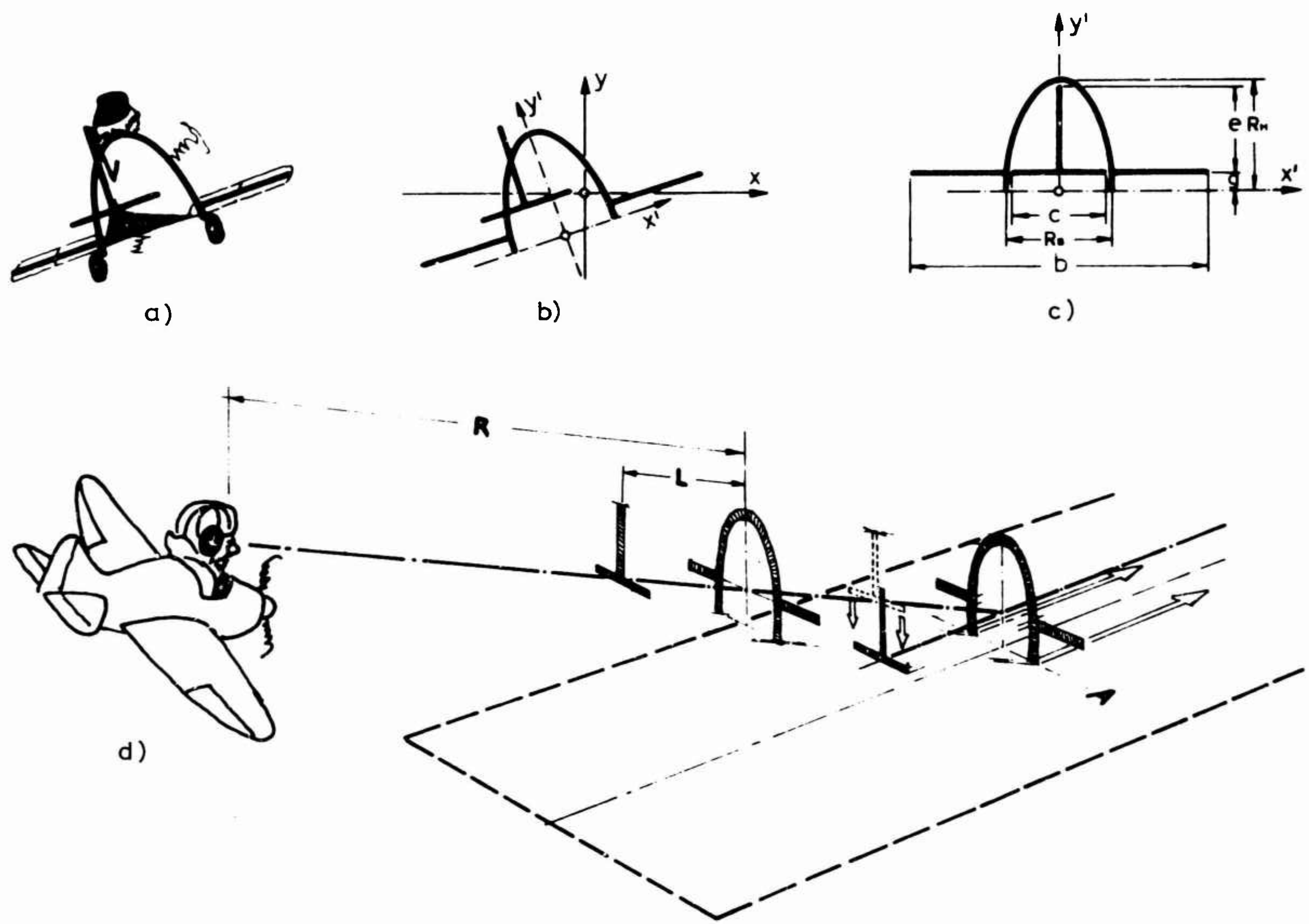

Fig. 2a-d: Display F

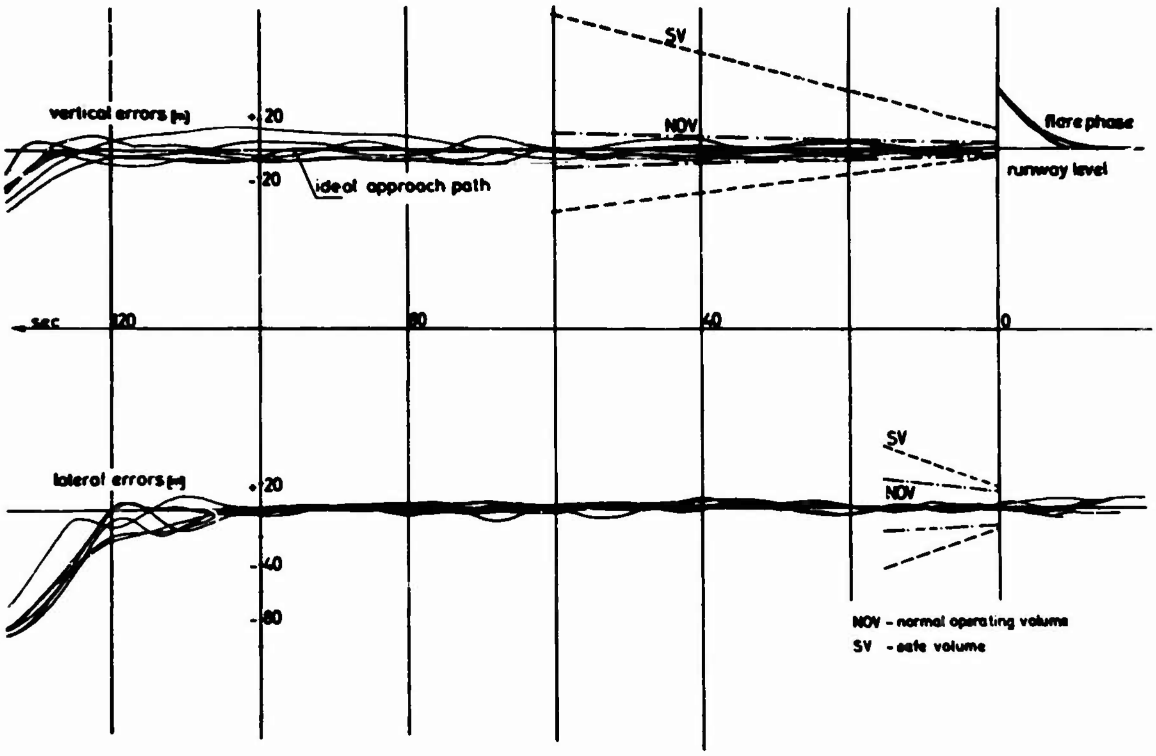

Fig. 3a: Test series for display B, aircraft A, pilot 2

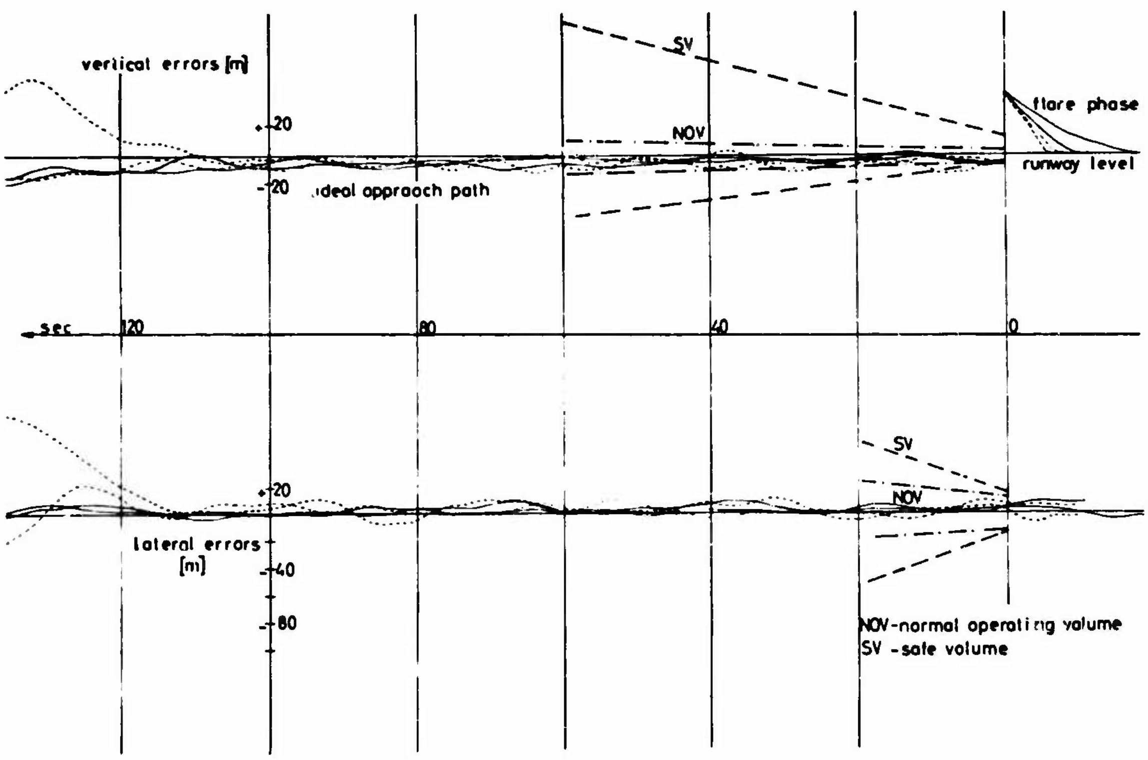

Fig. 3b: Test series for display F, aircraft A, pilot 2

IMPROVED DISPLAYS AND STABILIZATION IN GENERAL AVIATION AIRCRAFT

by

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A major cause of fatal accidents in general aviation is the non-instrument rated pilot flying inadvertently into adverse weather conditions. Since few airmen obtaining their Private Pilot Certificates go on to earn an instrument rating, a project was initiated by the Aircraft Development Service, Federal Aviation Administration, Washington, D. C., and carried out by the National Aviation Facilities Experimental Center, Atlantic City, New Jersey, to examine the effects of improved displays and automatic flight control to ease the cockpit workload of the single pilot flying on instruments. A corollary goal was to determine if such an improved cockpit environment would facilitate instrument training, both by means of the reduced workload and by enabling the student to obtain an early appreciation of the navigational concept of instrument flight.

A Link Model 60E instrument ground trainer was modified to incorporate a Cessna 182 fuselage for additional realism and in which a conventional instrument panel was installed. Eight experimental subjects, none of whom had had any instrument training, were trained to full instrument flight capability in the ground trainer which was configured to a typical cockpit environment. The successive phases of training undergone were an initial basic flight control phase, followed by complex maneuvering patterns, VOR navigation and approaches, ADF navigation and approaches, ILS approaches, and a final cross-country flight involving all three types of approaches.

When the subjects reached a level of competency in the simulator deemed adequate, they were given a flight check in one of the two single-engine aircraft available for this purpose; a Cessna 210 and a Piper Comanche 250. If a subject failed his flight check, more simulator training was undertaken, followed by a subsequent flight check.

The five subjects completing the training (three subjects dropped out for various reasons) required an average of 52 hours in the simulator and 7.6 hours in the aircraft in order to complete their final cross-country flight, which was often under actual instrument conditions. These training times, to meet the performance requirements for an instrument rating, compared favorably with records of March 1965 at the Aeronautical Center, Oklahoma City, which showed that 437 instrument ratings were issued with an average of 54 hours of flight instruction and practice and 17.5 hours of ground trainer instruction.

The Cessna simulator was then reconfigured to incorporate a three-axis autopilot, an instantaneous vertical speed indicator, and a pictorial navigation display wherein a small "bug" representing the aircraft was moved over an en route low altitude chart or a terminal area chart in response to VOR radial and DME distance information extracted automatically from the VHF navigation avionics. The Cessna Aircraft Company, Wichita, Kansas, modified the Cessna 210 cockpit instrument panel in a similar manner. The pictorial navigation display with its five inch diameter map was located in a vertical plane at the center of the instrument panel above the VHF avionics equipment.

To evaluate the effects of these displays and automatic flight control devices on reducing the pilot's workload in instrument flight the decision was made to utilize subject training time as a measure of the workload reduction when compared to the training times of the first group of subjects who learned in the conventional non-autopilot equipped simulator. Ten subjects varying in age, occupation, educational background, pilot aptitude and flight experience, were trained entirely in the simulator, to meet the same skill criteria as the control group. None had previous instrument flight experience.

Training consisted of four major levels of IFR flight instruction; namely, basic airwork including complex maneuvering pattern flight, VOR navigation and approaches, ILS approaches, radar vector approaches, and cross-country instrument flight.

The program required the subjects to utilize the autopilot to the maximum extent possible in all of these four levels of flight instruction in order to minimize the manipulative effort expended and allow the subject to concentrate fully on the navigation and air traffic control procedures learning.

Geographic orientation problems did not exist with the Phase II subjects since the pictorial display provided excellent geographic position information. Map scale selection became an item on the check-off list, however, since on several occasions subjects would forget to have the correct scale factor set in for the particular chart that was in the pictorial navigation display.

The problems that did emerge with this group of subjects were of the type just cited that involved improper equipment usage such as tuning a VOR frequency when an ILS approach was intended. The same problems were encountered with the exception of those associated with autopilot usage, with the Phase I group of subjects but they were overshadowed by the problems of manual stabilization and control and the interpretation of symbolic needles in the VOR and ILS course deviation indicators.

The Phase II subjects completed the entire IFR syllabus with an average simulator training time of 19.8 hours together with an average of 5.9 hours of performance validation in the aircraft for a total of 27.7 hours. Extracting ADF learning times from the Phase I data discussed earlier results in a comparable learning time of 40.9 hours in the simulator and 6.6 hours in the aircraft for the subjects using a conventional instrument panel in a non-stabilized aircraft for a total of 47.5 hours.

It should be noted that 2.4 hours of the Phase II subject's simulator time was devoted to flight under conditions with degraded equipment such as the autopilot turned off or the pictorial navigation display inoperative. Pilot performance under such manual simulated flight conditions reached a level equivalent to the Phase I control group. Additional training times were encountered with this Phase II group when after a seven month interval, caused by administrative problems, they were retrained to instrument flight proficiency in a non-stabilized simulator and aircraft not equipped with a pictorial navigation display, in other words, a conventional aircraft such as was employed with the Phase I group. An average of 4.9 hours of simulation time and 9.1 hours of flight time for a total average of 14.0 hours was required for these subjects to meet the instrument flight proficiency requirements.

The low training times for the Phase II group resulted primarily from the reduction in physical workload permitted by the autopilot and the ease of analyzing the navigation situation by use of the pictorial navigation display.

To determine the relative contribution of these two flight aids, a Phase III effort was undertaken in which eight subjects were trained in the simulator equipped with the normal flight instruments plus the pictorial navigation display. No autopilot or stabilization was employed. The pictorial navigation display used differed slightly from the first one by permitting both a "north-up" mode of operation and a "heading-up" mode. The first display was "north-up" at all times.

The four "north-up" subjects took an average of 26.1 simulator hours and 8.9 aircraft flight hours to attain instrument flight proficiency. The four "heading-up" subjects required 27.5 simulator hours and 9.2 flight hours respectively to achieve the same proficiency, indicating little difference between the two modes of pictorial navigation display operation.

The Phase III training times fall in between those of Phase I and Phase II subjects. A tabulation of the results is below:

	Average Total Training Time	% of Phase I
Phase I - Conventional	47.5	100
Phase I - Navigation display + autopilot	25.4	53.5
Phase III - Navigation display		
North-up	35.0	73.7
Heading-up	36.7	77.3

These data indicate an appreciable pilot workload reduction when a pictorial navigation display is employed in conjunction with normal instruments for flight under instrument conditions by the single pilot of a general aviation aircraft. An almost equal additional amount of workload reduction is experienced if the aircraft is stabilized and controlled by means of an autopilot.

The implications of these experiments are that general aviation pilots could more easily accommodate flight under instrument conditions if these flight aids were installed in their aircraft and also that their training to meet the standards of instrument flight proficiency would be facilitated.

THE COCKPIT AS A "BRAIN CENTER" TRADEOFF

by

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It has been determined that unburdening of the pilot and other aircraft operators in our time frame is a much desired goal. As we move toward higher performance aircraft and more complex flight profiles, more work is given the human operator (pilot) with less time to do it. In close examination of this problem we have developed an approach to develop system design in a well regulated methodology. The program that developed this concept is the Integrated Cockpit Research Program (ICRP). Its methodology is based upon rigorous analysis of the requirements within a technological time frame of all the variables that effect the pilot/aircraft interface.

Part of the philosophy behind unburdening the pilot and pushing the technology into integration inherent to the system has been a desire to delimit the challenge to the operator to be able to accomplish the job set out for him. With this new philosophy, the effectiveness of the mission is the focus and the proper balance between man and machine is that which is most effective in terms of mission success and, actually, that which is most cost-effective.

There are many avenues to establishing this new man/machine interface in the aircraft system with many advances in the technology of avionic elements. We are moving closer and closer to this realization. Some specific advances which are both in the making and will provide major accomplishments for this desired end are in the following:

a. Digital Flight Control

The development here is to provide an item such as an inertial velocity measuring system whose outputs would create a highly stable flight regime in almost all known segments of flight for both rotary wing and fixed wing aircraft. In addition to sensing the various axes of motion and their rates, the integration of the computational requirements by a digital computer becomes an inherent brain of the system.

b. Digital Monitoring of Avionics

This development would provide a continuous monitoring and sensing of avionic subsystem performance to reduce pilot evaluation and work load associated with assessing level of performance at any given time. An interesting concept of this area developed in the ICRP was the engine and propulsion subsystem performance monitoring or engine health monitoring. The giving over to the central computer complex the essential job of built-in-self-test procedures to the extent of not providing continuous information to the pilot would be a major breakthrough in the unburdening procedure.

c. Automation Enabling Target Detection

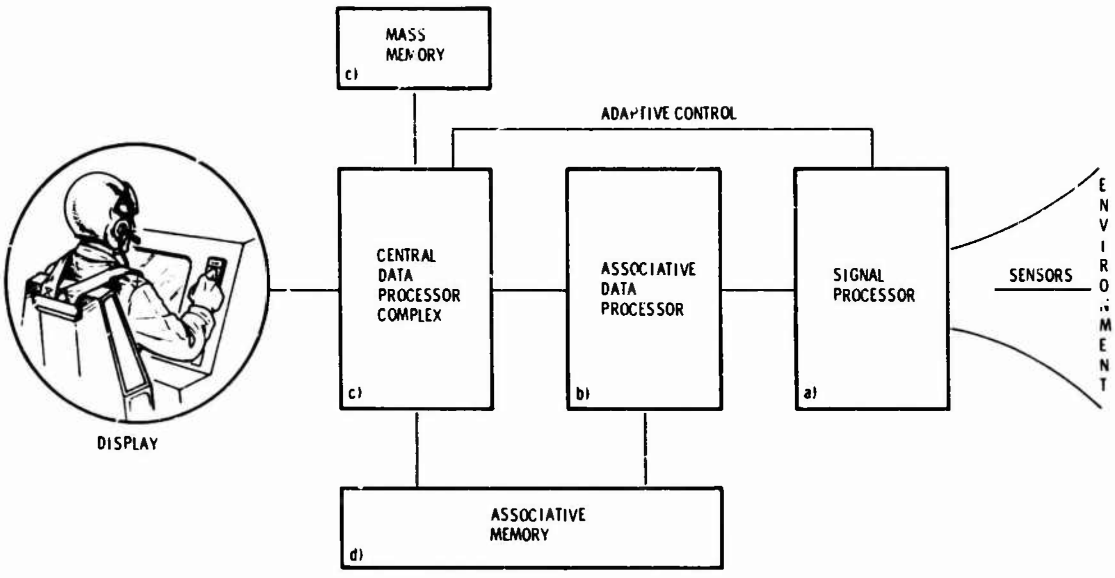
Much attention has been given to this area; a recognition of the major difficulties in both surveillance and weapon delivery problems. The ability to have a digital system acquire and act on targets automatically appears to be an answer to the limiting capability of the human being in the real time situation. The attached illustrations indicate these relationships and the functions of each "brain" in a real time system. It also illustrates the magnitude of the problem.

This discussion actually has been indicating the need for providing additional automation-computer system capability. "A brain", or many "brains", are needed in the concept to do the job. It appears from tradeoff studies presented that other "brains" are needed, than just the usual digital computer to achieve the optimal man/machine relationship in these complex systems and with complex requirements. Therefore, the cockpit becomes the "brain center" tradeoff area; it is the focus of system "actuation." By that we mean the decision making processes which occur as a result of feedback from total system operation. This results in an initiation of operating sequences and modes by a "brain". These brains may well be:

1. The pilot/co-pilot
2. The computer system
3. Adjunctive system elements.

Mass memory associative processors and associative memories.

A discussion and tradeoff of these areas are conducted in this paper to answer the main question of how well these "brains" relate and operate. This question will be discussed as a function of the technology level of sophistication available; a function of operator requirements and limitations and a function of operational requirements.



THE "BRAINS"

a) <u>SIGNAL PROCESSOR</u>

1. TIME/FREQUENCY SHAPING
2. SIGNAL QUANTIZATION

b) <u>ASSOCIATIVE PROCESSOR</u>

1. INTEGRATION, AUTO-CORRELATION
2. PREDICTIVE PATTERN

c) <u>CONTROL DATA PROCESSING COMPLEX (3×10^6 BITS)</u>

1. TRACKING DATA
2. EXECUTIVE SWITCHING & CONTROL
3. OUTPUT FORMATTING
4. COMPUTIONS
   i. ARITHMETIC
   ii. LOGICAL
5. SENSOR CONTROL AND RECUPSIVE ADAPTATION

d) <u>ASSOCIATIVE MEMORY (1×10^9 BITS)</u>

1. TARGET SIGNATURES
2. IDENTIFICATION CODES
3. PATTERN RECOGNITION

e) <u>MASS MEMORY (1×10^{14} to 1×10^{30} BITS)</u>

1. ALL PROGRAMS
2. THEATRE MAP
3. ORDER OF BATTLE

FUNCTION

Part of this paper was based on research supported by JANAIR via the U.S. Navy, Office of Naval Research, under Contract Nonr-4951-(00)

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CREW WORK-LOAD SHARING ASSESSMENT IN ALL-WEATHER, LOW-LEVEL STRIKE AIRCRAFT

One of the major factors which influences the layout of the cockpit and the design of cockpit displays and controls in an all weather low-level strike aircraft is the ability of the crew to deal efficiently with all the tasks associated with flying the aircraft, navigating and operating the weapons system.

The introduction of advanced technology engines, lighter/stronger alloys, microminiaturisation of avionics etc. have enabled the aircraft designer to reduce the necessary gross weight and size of military aircraft to meet a given operational requirement. The size of crew compartments have, in consequence, tended to be reduced. This trend, however, has not been emulated by the crew members whose physical dimensions have unfortunately remained substantially constant for some time now!

Optimum utilisation of available crew work space is therefore mandatory in the design of future aircraft cockpits. In addition the optimum division of workload between the members of a two man crew and the upper limit of workload which can be imposed must be studied. BAC are therefore conducting an experimental programme to investigate these aspects for an all weather low level strike aircraft.

The initial study was conducted on a simple and inexpensive wooden local cockpit mock-up (Fig. 1) pictorial only in respect of displays and system controls and equipped with a functional inter-communication system paralleled with a tape recorder. A time lapse camera was fitted covering the cockpits in which the Nav-Attack system represented an analogue system currently being fitted to a British Aircraft. The time lapse camera system comprised a 16 mm cine camera with wide angle lens controlled by a pulse unit. A time base of 1 exposure per second was used, this figure being chosen to facilitate analysis against time whilst being frequent enough to capture all movements.

The basic elements of the analogue Navigation/Attack system were as follows:-

Ground Mapping and Terrain Following Radars
Inertial Platform and Present Position Computer
Navigation Computer
Weapon Aiming Computer
Electronic Head-up display
Air Data Computer
Automatic Flight Control System
Air-to-Ground Missile control system
Electronic Countermeasures

Other aircraft systems represented in the layout included:

Engines
Hydraulics
Fuel
Electrical Generation and Distribution
Pressurization and Conditioning
Communication

In parallel with the design and construction of the cockpit mock-up, handling and crew notes were prepared. These covered detailed operation of the following:-

Part 1 Inertial Platform Alignment
Head-Up Display
Forward Looking Radars
Pre-Flight Navigational Switching
Navigation

(a) Flying to, and in flight storing of, distinations
(b) Fixing
(c) Tacan and Reversionary modes

Attack

(a) Bombs - retarded and unretarded
(b) Rockets or guns - air to surface
(c) Missiles - air to surface

Alan F. Daniels
Principal Engineer
B.A.C. WARTON.

Part 2 Pilots and Navigators Normal Operating Drills Missions. - a hi-lo-lo-hi interdiction sortie during which weapons were launched.

Part 3 Emergency Procedures.

The preparation of such detailed operating procedures and crew drills during the early feasibility studies of a particular aircraft help a great deal in integrating all aircraft sub-systems. Problem areas, incompatibilities and omissions are quickly highlighted for rededial action. Project Pilots and Navigators are given an early opportunity to inject their experience into detailed system design. Cookpit designers are provided with early "check lists" of items to be included.

During the exercise it became apparent that the tape recorder could be used to prompt the crew on the details of cockpit drills. To assist initial crew familiarisation the contents of the Pilots and Navigators cockpit drills - both actions and responses - were recorded on tape and played back to the subjects in the mock-up.

Analysis of the time lapse films and tape recordings has confirmed that this relatively inexpensive programme yields extremely useful data for establishing the ergonomic suitability of basic display and control layouts. The results of the initial phase stemmed mainly from detailed analysis of the time lapse films. Rapid processing together with available projection facilities gave the experimenters the opportunity to have a "quick look" at the film negative within a very short time of shooting. Running the time lapse film through the projector at 16 frames/second highlights areas of high activity which could, in real time, otherwise pass without notice. This "quick look" was followed by a detailed frame by frame analysis of crew hand movements. These were plotted against time for various phases of the flight.

This gave an easily assimilated pattern of the heavily loaded areas and by cross reference between the two cockpit patterns, the feasibility of transferring some of the Navigators load to the Pilot or vice versa became readily apparent. In the early stages, some "hand crossing" activities of which the subjects were strangely unaware were revealed. Following adjustment of position of various controls, a very easy procedure with this type of pictorial display, and some modification of the cockpit drills, the full exercise was completed.

The second phase of this work is intended to accomplish three prime objectives:

(a) To update the mock-up equipment fit to include a control and display arrangement for a digital nav/attack system more representative of systems to be fitted in the mid 70's.

(b) To validate the initial techniques and results by involving the crew members in more active representative tasks.

(c) To continue and expand the studies started in the initial phase.

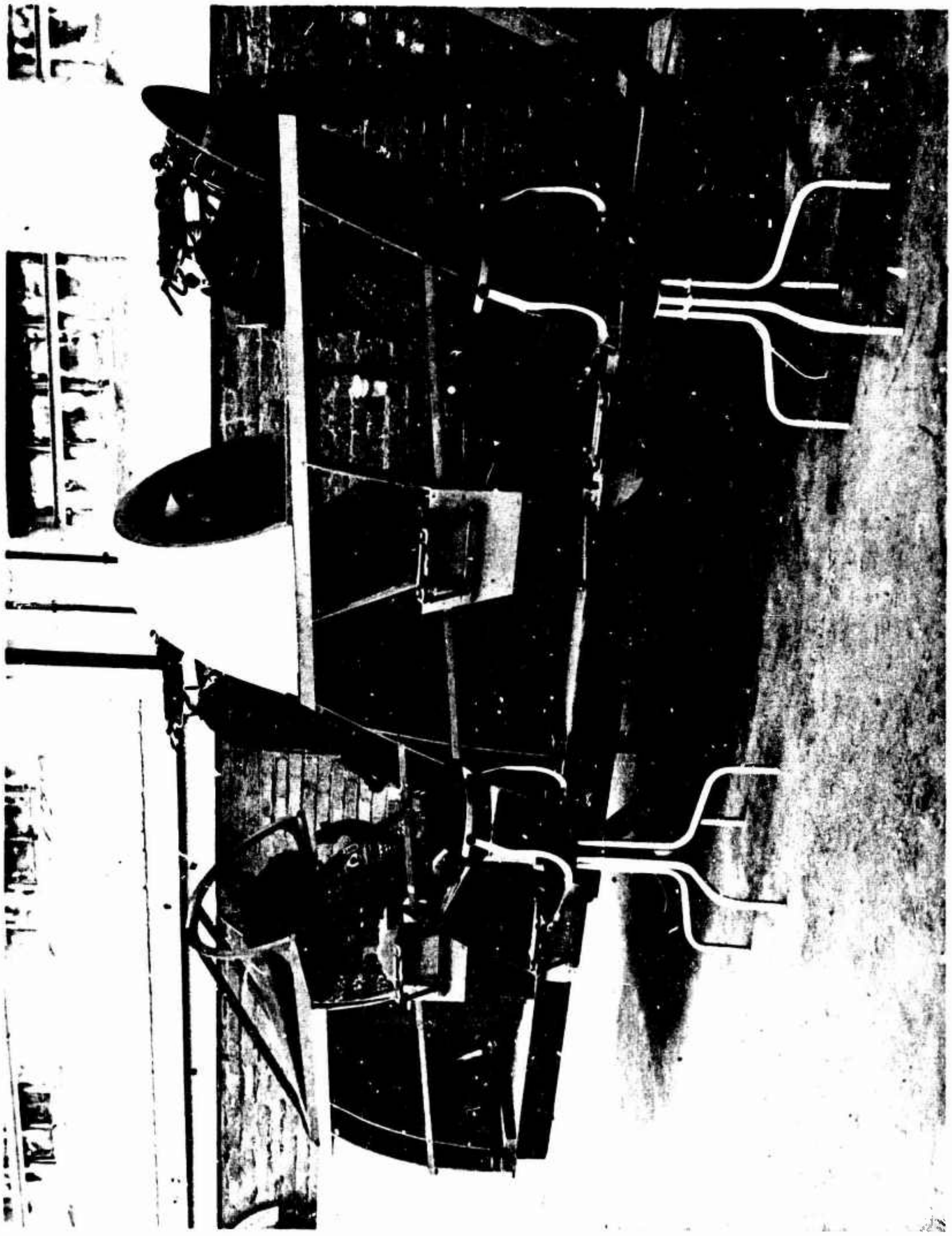

Figure 1. General Arrangement of Local Cockpit Mock-up.

A QUANTATIVE METHOD TO EVALUATE THE FAIL-SAFETY ASPECTS OF FLIGHT INSTRUMENTATION WIRING PATTERNS

Ir. J.M.H. van Vlaenderen

1 Introduction

As a safeguard against instrument failure it is common practice to provide commercial and military transport aircraft with two separate sets of flight instruments. This applies to indicators as well as data sensors and in many cases also to the flight director system. The object of this duplication is twofold namely :

1 To provide failure detection capability in cases where a slowover failure might lead the pilot astray.
2 To retain sufficient instrumentation after a failure, to complete the flight safely.

The efficiency with which these objects are met depends to a large extend on the interconnection pattern between the various data sources, instruments, computers and control facilities. For example sources and indicators on the left and right can be interconnected as follows :

(1) Straightforward when corresponding indicators on the left and right panel are connected to the source on the same side.
(2) Parallel when corresponding indicators are connected to the same source.
(3) Crossed when indicators are connected to the opposite source.

A mixture of these ways of interconnection can be and is often used. Inputs to a single flight director or autopilot computer can be taken from the left, the right or partly from both sides. In case of dual computers the same possibilities as quoted above for instruments apply. Control facilities such as mode-, course-, and heading selectors can be located centrally or divided between the left and the right side. Add to all this that switches are often used to restore faulty indications after a failure and it should be obvious that an almost unlimited variety of lay-outs is possible. In fact, from an inquiry conducted by NLR on the flight instrumentation systems, encompassing eleven airlines and manufacturers all the different companies appear to have developed their own interconnection schemes.

2 Diagrams

An investigation has been conducted concerning the fail-safety aspects of flight instrument system wiring configurations. The investigation covered the electrical instruments only, while it is in this part that the greatest variety and complication in interconnection exists and as it is also the part most vulnerable to failures. The following components are normally involved :

Components	abbreviation
- 2 vertical gyros	VG
- 2 nav-glide slope receivers	NAV/GS
- 2 directional gyros	C
- 2 horizon flight director instruments (sometimes with localizer and glide slope indications)	H/FD
- 1 or more standby horizons	SB HOR
- 2 pictorial deviation indicators (in most cases with compass and glide slope indications)	C/PDI
- 2 or more radio magnetic indicators	RMI
- 1 or 2 flight director computers	FD COMP
- 1 autopilot	AP

In addition remote heading selectors (HDG SEL) or course selectors (CRS SEL) are sometimes used instead of the more commonly used select knobs on the PDI or RMI.

Fig. 1 shows the listed components as interconnected by one of the companies from which information has been obtained. In the figure circles represent instruments, boxes are data sources, computers or remote controls, switches are in the normal position. Data transmissions are represented by single lines irrespective of the number of wires involved. Switches or controls are drawn on the side of the pilot to which they are handy. Switches or controls in the middle are within easy reach of both pilots.

3 Classification

A general classification of lay-outs is as follows :

(1) Split cockpit.
Each pilot has an independent and complete set of instruments often including flight director system and selection and switching facilities. The aircraft can be flown equally well from either side. Figure 1 is an example of a split cockpit.

(2) Common cockpit.
Both pilots have access to centrally located controls. The interconnections are mainly in parallel. The aircraft can be flown equally well from either side.

(3) Captain-is-King cockpit.
Selection and switching facilities are located mainly on the left side. The aircraft can best be flown from the left-hand seat.

In most cases actual systems are more-or-less a mixture of the above basic lay-outs.

4 Evaluation methods

The objects of the study were to compare the relative merits of various systems in use and to develop "optimum" configurations with regard to fail-safety. To avoid the usual subjective arguments, objective numerical methods based on simple straightforward rules have been developed.

With respect to the first aspect of safety, i.e. the possibility of failure detection, the following philosophy has been applied.
The need for rapid detection is greatest when a failure causes inadvertent deviation from the intended flight path near the ground. Therefore the critical cases are defined as the approach to land on either flight director or autopilot or the climb after take-off on the flight director in combination with a slowover failure affecting the flight director or autopilot as appropriate. Such a failure has been refined as a critical failure. Tables have been devised with decreasing probability of detecting critical failures. For the flight director case the table is as follows :

Non-detection probability score	1	2	3	4
(i) Is the main indication of the relevant basic flight reference correct?	yes	yes	no	no
(ii) Is there a discrepancy between the main and standby indication of the relevant basic flight reference?	yes	no	yes	no

The highest probability (4) exists when the flight director, the main indicator and the standby indicator are all affected by the failure, and consequently do not show conflicting information. It will be of some help (3) if the standby indicator is unaffected and hence disagrees with the main indicator. Still clearer (2) should be a conflict between the main indicator and the flight director. The best case (1) is obviously when the main indicator is in agreement with neither flight director nor standby indicator.
A comparable table has been devised for the autopilot case.

Of all systems left- and right-hand panels have been scored with regard to detection probability for all relevant component failures. For each basic flight reference, i.e. attitude, radio deviation or heading scores have been added according to the rules of probability and the total scores were used to grade the various systems with respect to fail-safety.

The second aspect, namely the loss of information after a failure is not related to probability, and a different scoring system based on penalty marks has been devised. Information loss will occur after any component failure and the term critical failure does not apply to this case. The scoring table for the flight director case is as follows :

Penalty mark	0	1	2	3
(i) Are correct indications of the vital basic flight references still available?	yes	yes yes	no	no
(ii) Is the flight director indication correct?	yes	yes no	yes	no
(iii) Are the non-vital basic references, i.e. heading for the approach or beam deviation for the initial climb, still available?	yes	no yes	-	-

The penalty depends on the amount of correct indications of all basic flight references (attitude, heading, beam deviation) and correct FD indications, still available. When all these indications are still on hand, for example through duplication, no penalty is given even though there may be wrong indications that have to be disregarded. One penalty mark is given when the flight director or a less important basic flight reference, i.e. heading during the final approach or beam deviation during the initial climb are no longer available. When a basic flight reference is affected while the flight director remains correct a flying task could still be performed but as there is no proper monitoring two penalty marks are alloted. Finally, when the flight director as well as the indicator of a vital basic reference are faulty, three marks are given. The availability of switches to restore indications has been accounted for by an appropriate reduction in penalty marks. Again a comparable table has been made for the autopilot in the approach case. As in the case of failure detection total scores have been added up for the different flight references of each system.

5 Basic patterns

In addition to the evaluation of existing systems the scoring system has been used to obtain "best" interconnection patterns with minimum scores. All the possible basic patterns with one flight director computer are shown in fig. 2. The same number of basic patterns can be obtained with two flight director computers. The components involved in the example are : two sources, two main indicators, two standby indicators, one flight director computer and an autopilot. The flight reference represented could be either attitude, heading or beam deviation. Table 1 shows the scores for each of the patterns with regard to both fault detection and survival. Particularly with regard to fault detection there appears to be a large variety in scores. The outstanding arrangements appear to be 1.3, 1.4 and 1.6.

6 Optimum systems

By applying the results of the basic patterns to complete systems, lay-outs have been achieved which have significantly better scoring results than any of the operational systems evaluated. Figure 3 shows the resulting lay-out with one flight director computer. All the interconnections are according to basic arrangement 1.4. This common arrangement was prefered over the split arrangement 1.6 because, contrary to 1.6, it is not necessarily tied to crew duties, while the difference in score is so small as to be insignificant. A similar lay-out for two flight director computers has also been constructed using the best basic lay-out for two flight directors. Surprisingly this turned out to be a common arrangement, which is contrary to current practice where systems with two FD computers all are split arrangements.

7 Compiled results

The compiled scoring results are presented in abbreviated form in table 2. Total scores for eleven current systems together with the NLR reference systems are presented for the three flight parameters. The original complete tables contain in all 20 items the failure of which can affect the fail-safety aspects under consideration.

For the failure detection case the reference systems show the lowest score in all cases. This is accomplished through the use of the optimum basic patterns which exploit the full monitoring potential in addition to avoiding series interconnections and remote systems.

With regard to loss of information it should be noted that the score for the actual systems relates to the number of switches given in the column. The score for the reference systems is that obtained without switching and the number of switches (between brackets) is the number necessary to reduce the score to zero. As it turns out the score with respect to loss of information is also lowest for the reference systems. Apparently, the measures to increase detectibility and survivability of faults are compatible.

8 Conclusions

Summing up the following conclusions have been reached :

1 There is a wide variety in wiring patterns and in switching.

2 Two aspects of flight safety are closely related to the wiring patterns between flight instruments and associated equipment. These aspects are :
   (1) The conspicuity, after a failure, of such faulty indications that may result in an inadvertent slowover manoeuvre.
   (2) The degree by which the instrumental information is reduced as a result of a failure.

3 From an analysis of basic wiring patterns, using an objective evaluation method developed for the present study, reference interconnection schemes have emerged with excellent qualities as regards the above aspects. In contrast to many current systems, left-hand and right-hand sides of the panel are completely equivalent. As a consequence the reference systems can be used with any task allocation that might be desired. This should be a major advantage providing both flexibility and the possibility of standardization. It is believed that by applying these reference schemes or the philosophy leading up to them, most current flight instrument systems could be improved just by changing the interconnection pattern. The method is also recommended for application to future systems.

TABLE I: Analysis of Basic Wiring Systems Scoring Results

	ANALYSIS	FAILURE DETECTION										LOSS OF INFORMATION WITH RECOGNIZED FAILURE						
	FLIGHT CONDITION	FD APP.			FD CLIMB			AP APP.			TOTAL	FD APP.		FD CLIMB		AP APP.		TOTAL
	CREW POSITION	1	2	3	1	2	3	1	2	3		1	2	1	2	1	2	
ONE FD COMPUTER	SYSTEM 1.1	3	3	3	3	3	3	1	1	1	55	1	1	1	1	0	0	4
												0	0	0	0	0	0	
	1.2	3	3	3	3	3	3	3	3	3	81	1	1	1	1	1	1	6
												0	0	0	0	0	0	
	1.3	1	1	1	1	1	1	2	2	2	10	0	0	0	0	0	0	6
												1	1	1	1	1	1	
	1.4	1	1	1	1	1	1	2	2	2	10	0	0	0	0	0	0	4
												1	1	1	1	0	0	
	1.5	3	1	1	3	1	1	3	2	2	18	1	1	1	1	1	1	6
												0	0	0	0	0	0	
	1.6	1	3	1	1	3	1	2	1	1	8	0	0	0	0	0	0	4
												1	1	1	1	0	0	

TABLE 2: Total Fail-Safety Score for Various Systems

	1 FD COMPUTER								2 FD COMPUTERS				
COMPANY	A	B	C	D	E	F	G	NLR	H	I	J	K	NLR
AIRCRAFT TYPE	DC-8	CARAVELLE	B 707	B 707	B 727	DC-9	CARAVELLE	REF 1	DC 9	CARAVELLE	B 727	CARAVELLE	REF 2
ATTITUDE REFERENCE													
FAILURE DETECT. SCORE	18	18	18	24	18	14	18	10	12	12	12	12	3
FAILURE SURVIV. SCORE	16	9	25	0	16	17	29	4	29	29	23	23	4
NR OF SWITCHES	0	3	1	3	1	0	0	(2)	0	0	1	1	(2)
HEADING REFERENCE													
FAILURE DETECT. SCORE	25	16	22	12	15	16	9	2	15	10	10	10	2
FAILURE SURVIV. SCORE	18	2	10	0	2	4	4	2	6	4	3	1	2
NR OF SWITCHES	0	2	3	3	3	3	0	(2)	0	0	1	3	(2)
DEVIATION REFERENCE													
FAILURE DETECT. SCORE	128	54	24	24	24	10	10	9	8	8	8	8	2
FAILURE SURVIV SCORE	14	0	14	14	14	0	23	2	13	23	18	14	2
NR OF SWITCHES	2	2	2	2	2	0	0	(2)	0	0	1	2	(2)

SPLIT COCKPIT

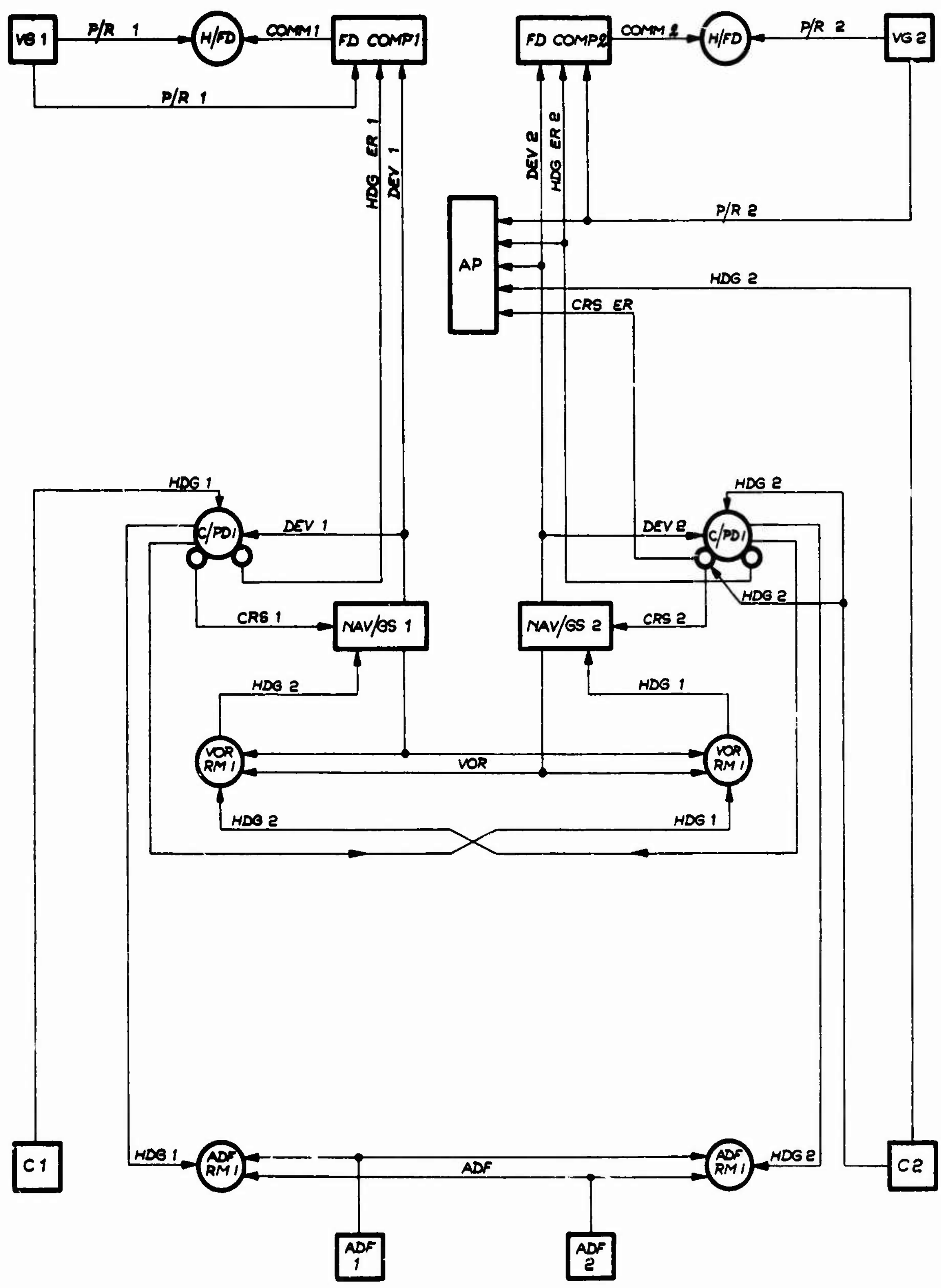

Fig. 1 Company I, Caravelle

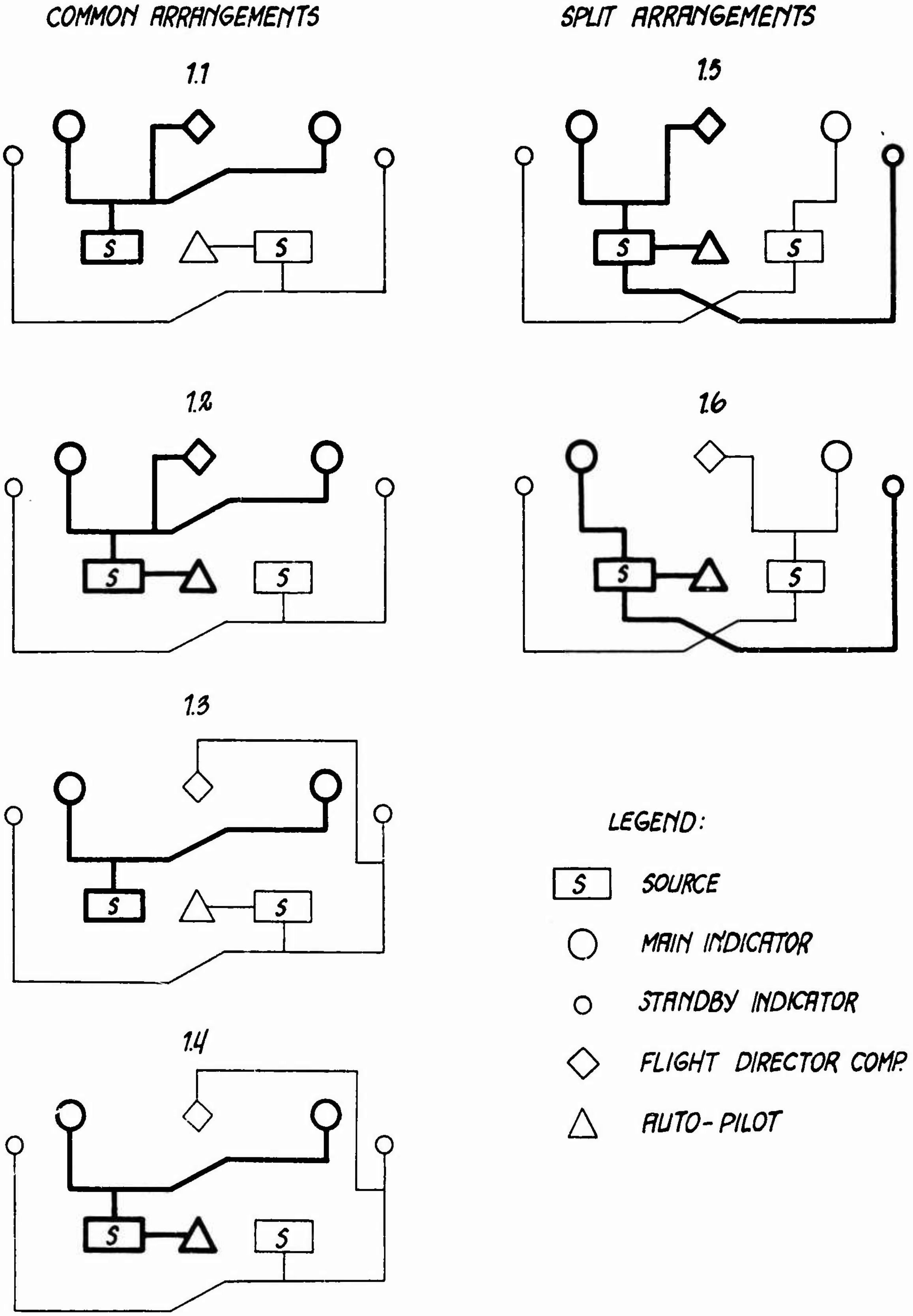

Fig. 2 Cockpit Instrumentation - Basic Wiring
One Flight Director System

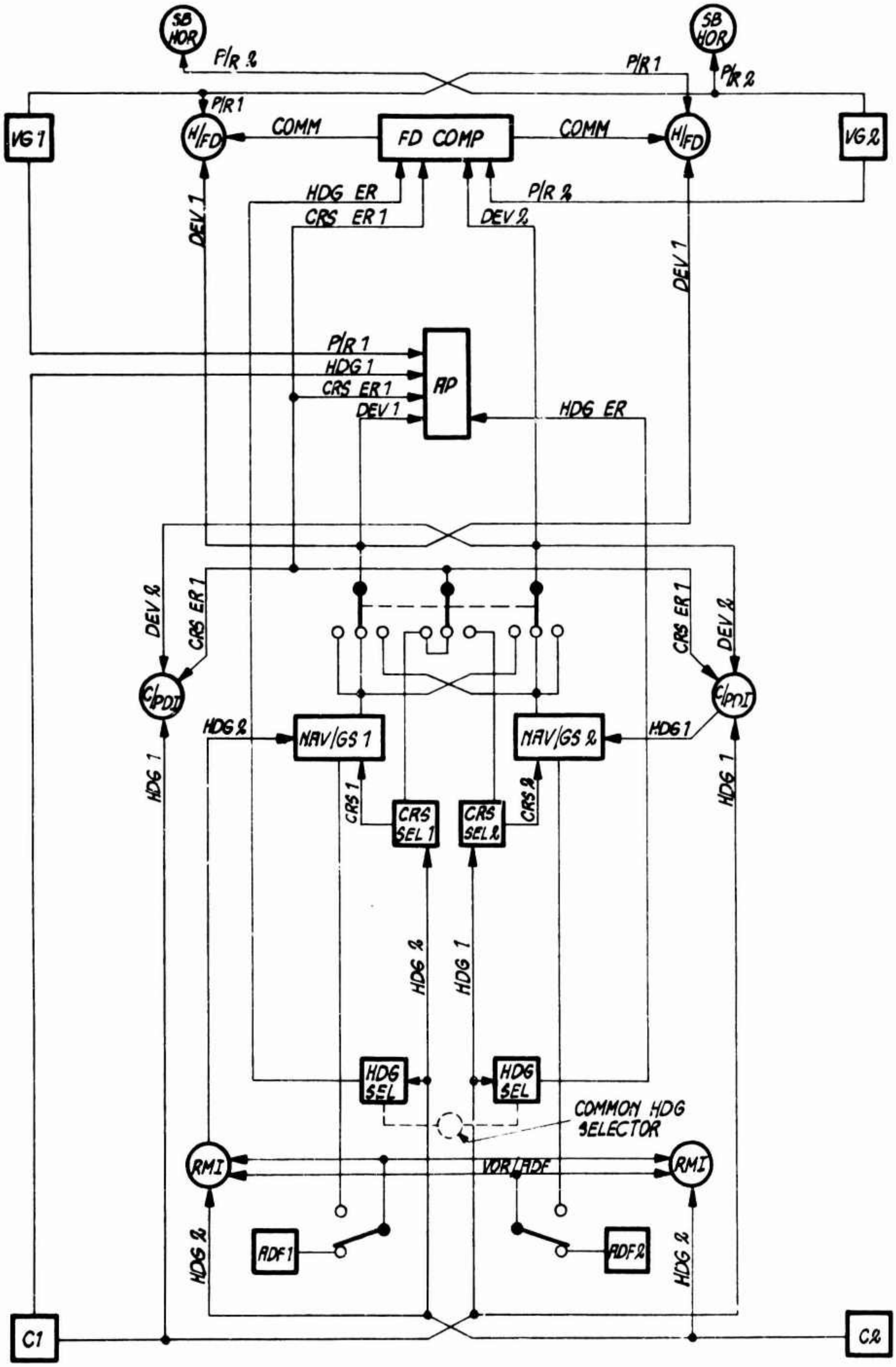

Fig.3 NLR Reference System 1 (1 FD Computer)

A DEVELOPMENT IN COCKPIT GEOMETRY EVALUATION*

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and

LCDR Francis L. Cundari, USN
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In this day of significant improvements and breakthroughs in most technologies, we have not taken full advantage of available scientific tools to evaluate the cockpit subsystem. Thus, we have been continually limited by inaccurate predictions, long flow times, and high costs.

Among the key items that must undergo evaluation early in vehicle development programs is cockpit geometry, the physical layout of the entire crewstation complex–displays, controls, seats, personal equipment, windshield/canopy/windows, interior surface shape. and openings for ingress and egress. Providing a cockpit optimized for safe and efficient physical utilization by flight crews still depends on approximate evaluation methods. Currently, drawing reviews, mockups, flight simulators, and prototype flight test techniques are used to evaluate cockpit geometry. These methods have been refined over the years and do produce useful data, yet they cannot take into account the full variability in flight crew anthropometry (Fig. 1). In addition, dynamic evaluation requirements are not met until flight simulation and flight tests are conducted. This usually occurs too late in a product program for easily implementing any needed redesign. Thus, we still produce cockpit subsystems with geometry problems; for example, the F-111 wing-sweep control lever travel could be reduced, according to Major R. K. Parsons, a key member of the USAF F-111 Category 2 test force (Ref. 1).

The overall problem lies with our present inability to handle the large mass of available anthropometric data and with the lack of some specific human physical capability data. To solve this problem, The Boeing Company, together with the Joint Army Navy Aircraft Instrumentation Research (JANAIR) Program Working Group, is engaged in the development of a cockpit geometry evaluation method using computerized man-machine model techniques (Ref. 2). This computer program will enable the cockpit subsystem designer to examine, early in a vehicle design program, competing crewstation geometries and determine the ability of any size operator to perform all required physical functions.

This Boeing/JANAIR research effort is projected as a six-phase study (Fig. 2). The purpose of the study is to develop a modeling technique that capitalizes on the large capacity and the high speed of the electronic digital computers. The model will dynamically simulate any human form, any cockpit geometry, and any flight-crew movement necessary to operate the cockpit being evaluated. The resulting computer program will, for the first time, permit the designer to use effectively the vast quantity of anthropological and ergometric human data to help optimize crewstation design (Fig. 3).

Phase I of the program will be completed by January 1969. The accomplishments of Phase I will include:

- A baseline cockpit geometry evaluation computer program that incorporates a mathematical model of a 23-joint articulated stick-man (BOEMAN-I) of any desired size.
- Anthropometric data to describe the linear dimensional characteristics and angular excursion limits of the United States pilot population.
- Laboratory data describing joint movements during typical flight maneuvers as well as validation of the BOEMAN-I model against these data.
- The development of computer communication techniques to automatically display evaluation results in tabular form, curvilinear and bar graphs, or alpha-numeric notation.

The major portion of Phase I is centered about the man-model. This is a baseline mathematical model of a 23-joint pin-link manikin (Fig. 4). The stick-man is fashioned after a similar manikin described by Dempster (Ref. 3). Information from existing literature is employed whenever possible to describe the human characteristics and capabilities that BOEMAN-I should simulate. Additional data required to develop BOEMAN-I, not available in current literature, is being derived by Boeing. These data describing BOEMAN-I are summarized in a human data document (Ref. 4), which will be kept current with BOEMAN development. The human data collated thus far include such items as conventional anthropometric surveys, bivariant data of selected anthropometric measures, link dimensions (distance between pin-joint centers) as a function of conventional anthropometric measures, segment and total body centers of gravity, segment masses, volumes and densities, mass moments of inertia, joint angular excursion limits, and visual envelopes.

Additional data are required to complete the outlined 6-year program to accurately develop BOEMAN. The current view of these data requirements is outlined in a new data requirements document (Ref. 5). It is anticipated that necessary special research programs will be conducted by military, university, and industrial laboratories under the guidance of the JANAIR Program Working Group. These additional data will include both female and male physical characteristics and capabilities by body build, ethnic origin, training, and age. Figure 5 summarizes some of the key data needed, the estimated time required for development, and the critical date the data is needed for the orderly progress of this total project.

The computer program for the evaluation of crewstation geometry will contain a number of sections that are being developed in modular form to facilitate modification. The sections will then be integrated for processing on the CDC 6600 computer.

The investigation of the baseline man-model, a major portion of the computer program, required examination of a number of possible approaches. The present heuristic man-model uses a series of predefined decisions to establish feasible joint locations in space during operator (BOEMAN-I) movements. Alternate man-models are being investigated, which includes the development of a constrained optimization technique.

The pre-analysis section of the computer program is used to establish whether the specified cockpit control is within the reach envelope of the operator. This eliminates the synthesizing of joint locations for noncompatible link dimensions and control locations.

A separate software section of the computer program is employed to assess visual interference between the operator and the object to be viewed. Once visual obstructions are identified, a determination proceeds to establish (1) whether another head position is possible in order to view the object and (2) the amount and direction of such head displacement.

The summations of physical parameters are accomplished in yet another section of the computer program. These

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*The research being reported in this paper was accomplished with the support of the Office of Naval Research, Contract N00014-68-C-0289, Project No. NR 213-065/11-16-67 (Code 461).

summations include items to be used in comparing alternate workspace geometries. The parameters include such items as head, hand, and eye displacement or deflections and their summations over a total task, mass displacement (assuming the mass is concentrated at the centroid of a segment) of each segment and their summations over a total task; and the total body and the amount of body or segment displacement involved in visual interference elimination.

Cockpit geometry modeling efforts, another section, parallel BOEMAN development. The sophistication of geometry detail progresses from simple straight lines and plane surfaces in Phase I to full-shape representation in Phase VI. For software development purposes, the geometry of the Boeing multimission flight simulator, Fig. 6, is being used. Since the geometry and associated flight-crew procedures are unique to the cockpit subsystem being evaluated, a set of directions for identifying and specifying these computer inputs is being developed.

Models require validation. Toward this end, BOEMAN, cockpit geometry model instructions, and task movement instructions are being validated initially against flight simulation results. Final validation will be done by comparing model predictions with flight-test results from a variety of aircraft, including helicopters. The Boeing multimission simulator is being used to develop initial validation data (Ref. 6). It is representative of advanced fighter/attack aircraft, and can be configured as a single- or tandem two-place cockpit subsystem. To ensure a useful sample of validation data, the simulator has been reconfigured to have some geometry problems of varying degrees of complexity in addition to geometry with no problems. Validation is being accomplished by filming flight crews composed of men of various sizes flying the simulator, and comparing the computer-synthesized joint-locations with those of humans performing the same task.

The commonality between BOEMAN and flight-crew movements is being statistically analyzed, initially using simple tests of hypotheses on means for BOEMAN-I and multivariant analysis of variance methods for later versions of BOEMAN. The communication of the commonality (or deviation) of synthesized and actual motions is accomplished by superposing computer-synthesized activity, portrayed with computer graphics techniques, on the real flight-crew film. Any differences between model movements and those of real flight crews are readily apparent when the superposed movies are viewed.

The man-model software section is continuously being refined and will possibly have an entirely different approach incorporated as alternate model techniques provide greater accuracy and/or speed. Although the initial step has been taken, a sizable effort is yet to be completed in the remaining phases of the research program.

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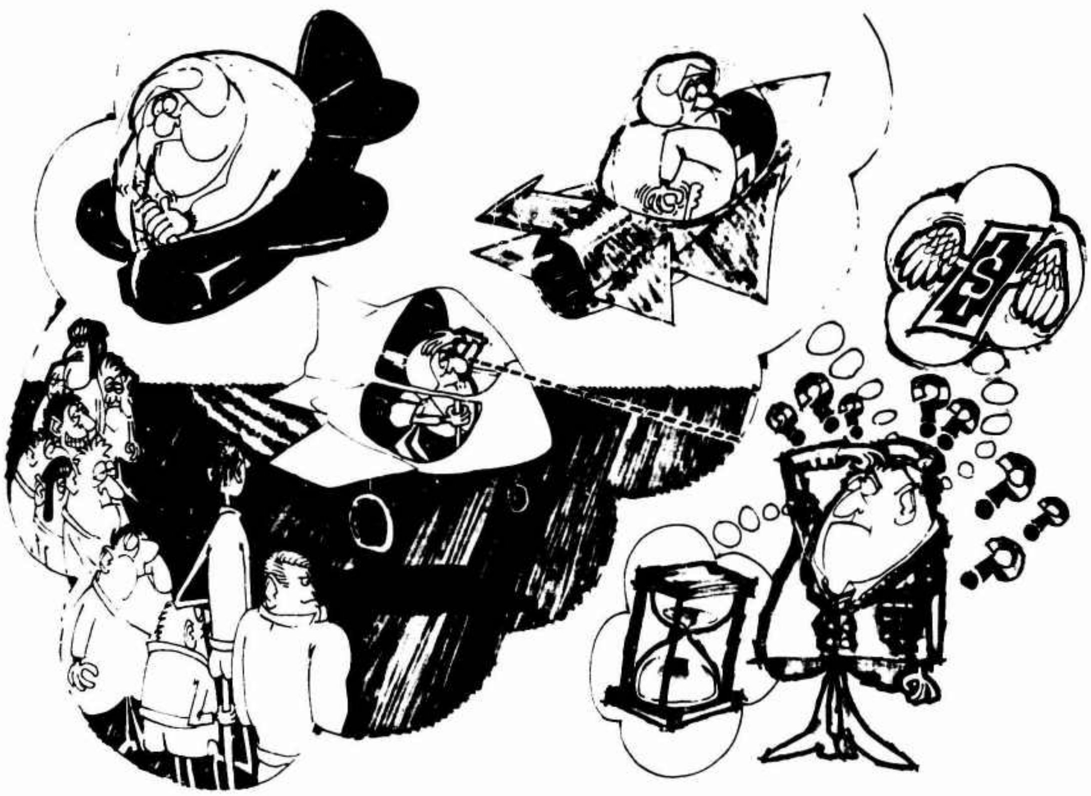

Fig. 1 The Problem

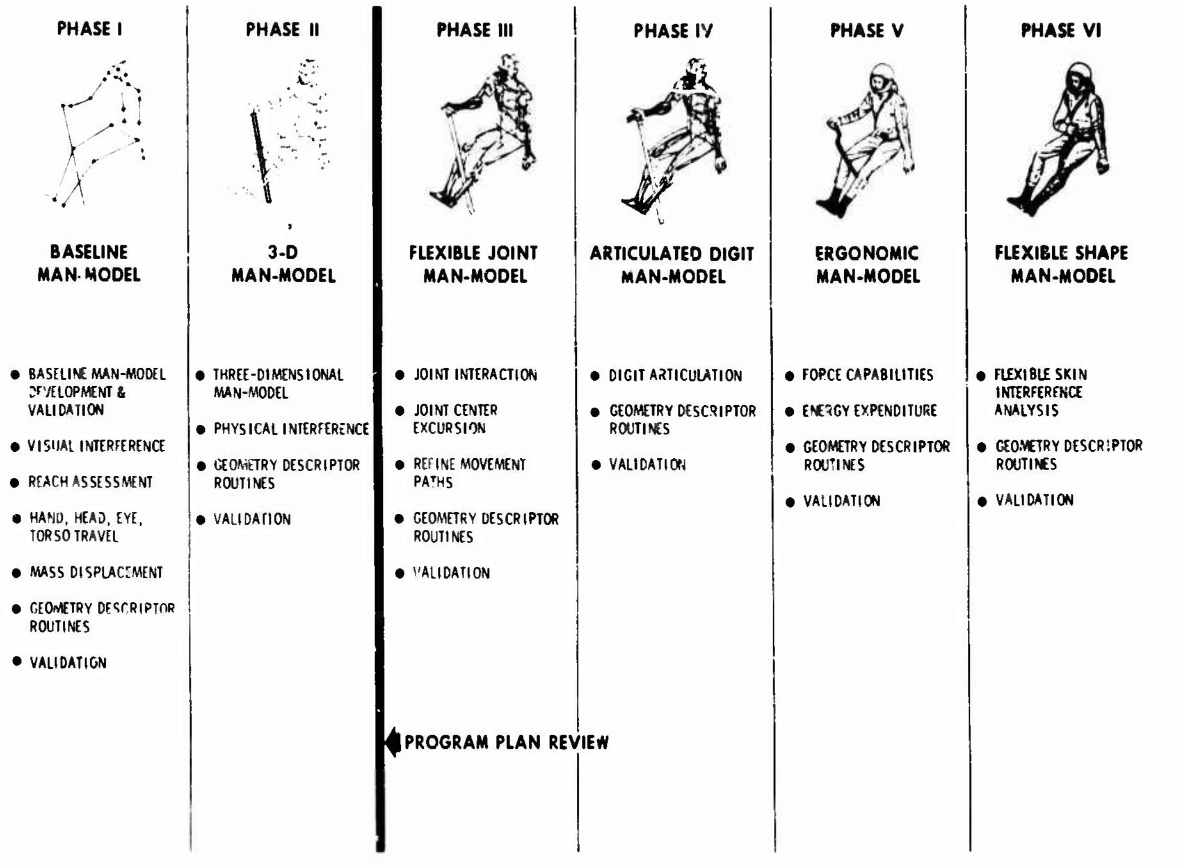

Fig. 2 Research Plan Summary

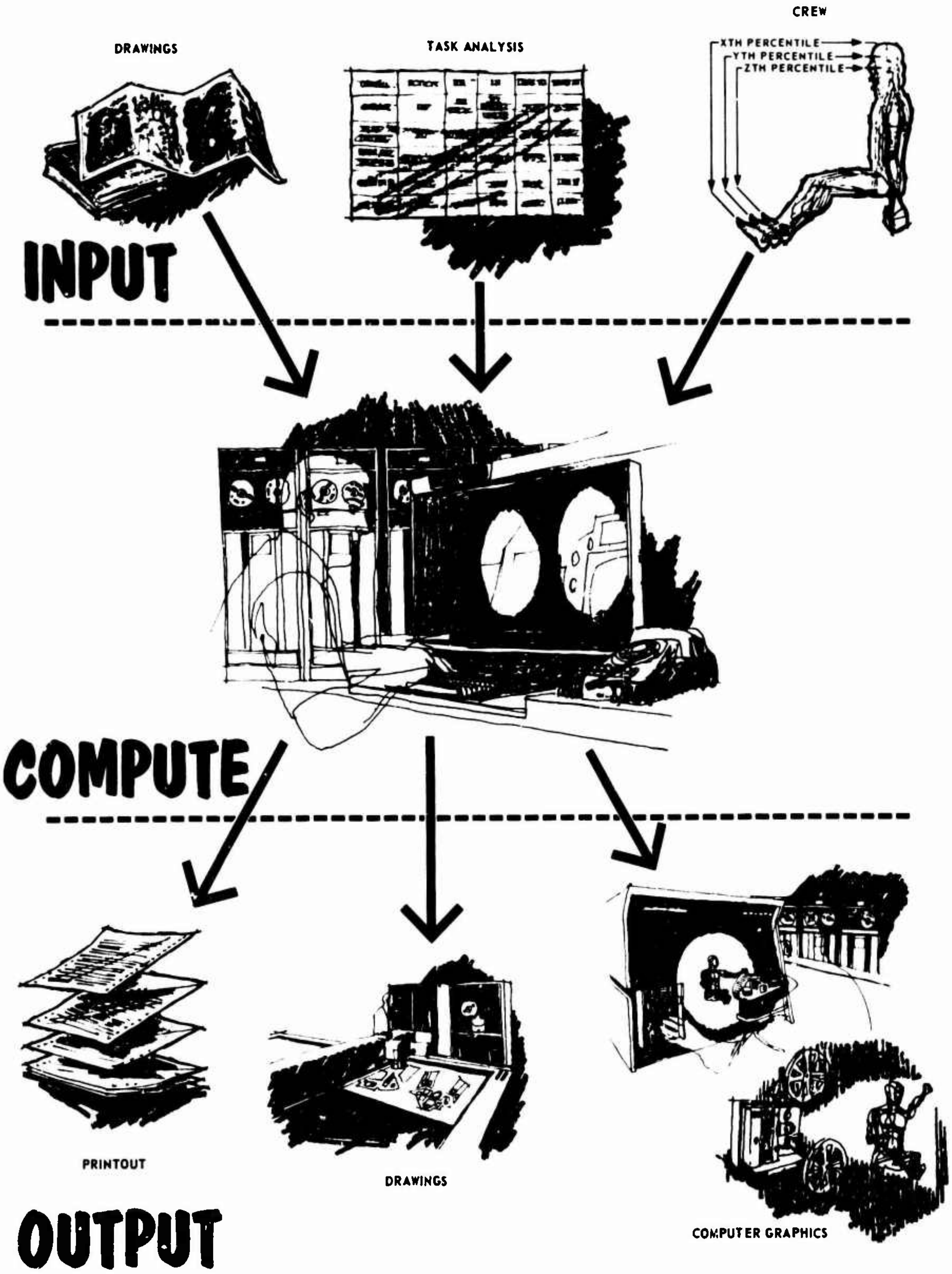

Fig. 3 Crewstation Geometry Evaluation

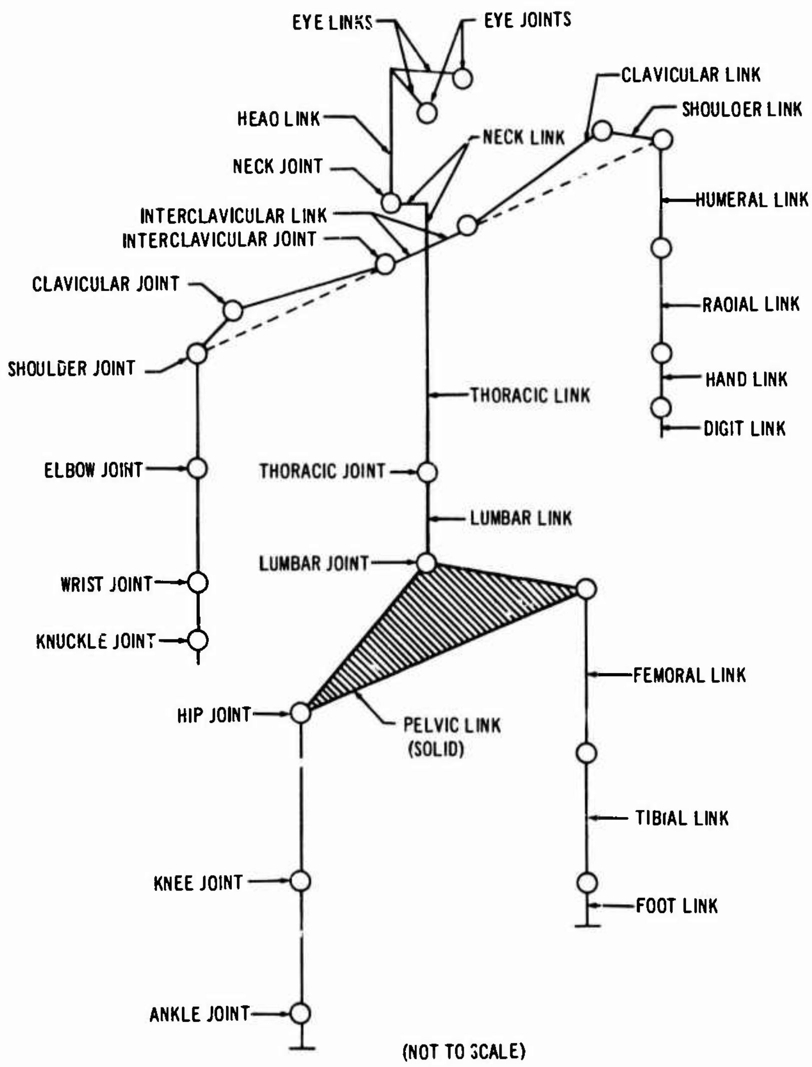

Fig. 4 BOEMAN-I-Baseline 23-Joint Flight-Crew Model

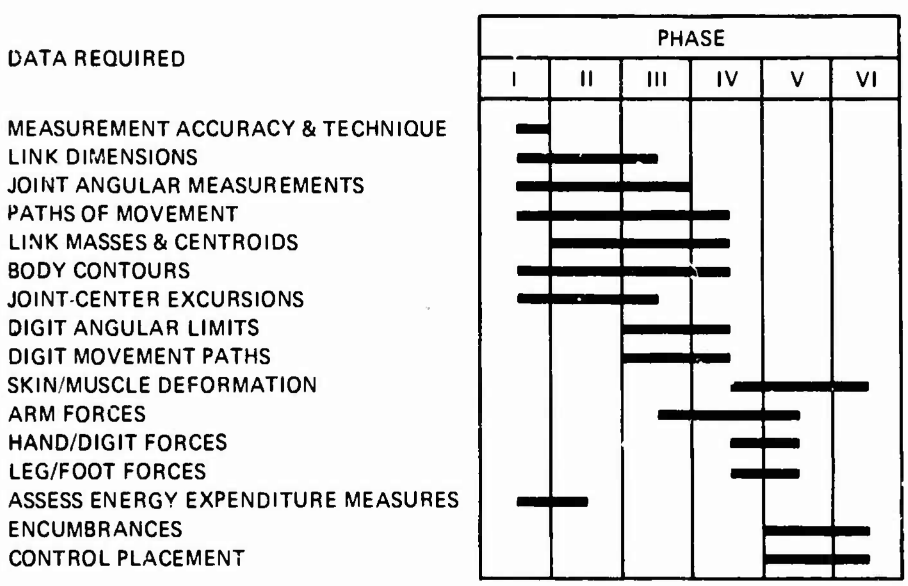

Fig. 5 New Data Requirements

Fig. 6 Boeing Multimission Simulator for Validating BOEMAN-I

THE UTILIZATION OF MILITARY ANTHROPOMETRY FOR AIRCRAFT COCKPIT DESIGN

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An important concept in the area of military research and development is represented by the so-called systems approach. According to this concept, the man together with his equipment, whether it be personal equipment he is wearing or using or a machine he is operating, is considered to be a man/equipment system. A basic requirement for the effective use and operation of such a system is that the man and the equipment be compatible.

Effective human engineering plays an important role in achieving such compatibility. Since anthropometric data constitute a basic requisite for defining the elements of body size in the human engineering of man/equipment systems, anthropometry represents an essential input to the development of such systems.

Anthropometry is the measurement of the human body. Since effective human engineering requires the use of body size data on the specific population for which the equipment is intended, military anthropometry is one important source of the information necessary for the design and sizing of equipment and materiel to be used by military forces.

Anthropometric data are collected by measuring large, representative samples of the military population. Through the compilation, processing, analysis and synthesis of such data, it is possible to provide a metric description of the military population for general use in the design and human engineering of military equipment and materiel, and also for specific application in the design, sizing and tariffing of clothing and individual equipment.

The concept of a man/equipment system is particularly important with respect to the pilot and his aircraft. The exacting demands placed upon the pilot for the successful completion of his military mission require a high degree of compatibility between the pilot and the cockpit within which he operates. The layout and design of a suitable cockpit involves consideration of many factors such as the environment, vision, hearing, location of instruments, displays, and controls. Therefore, consideration of the body size of the pilot is by no means the only factor which should receive consideration, but at the same time, it has an important bearing upon the integration between the man and the aircraft. It is for this reason that the use of anthropometric data is a basic part of cockpit geometry. In other words, the pilot should "fit". Ideally, the cockpit and the aircraft should be sized and designed to fit the pilot. Unfortunately, the general approach in the past has been to build the aircraft and then, sometimes literally, stuff the pilot into his operating space.

The utilization of military anthropometry for aircraft cockpit design will be discussed in this paper in two phases. The first will be the collection and analyses of anthropometric data. The second part will consist of some comments on the application of these data in aircraft cockpit design.

Collection and analyses of anthropometric data on military personnel have been carried on actively in the United States for over twenty years. However, new anthropometric surveys have been conducted recently on all of the Armed Forces of the United States. The new data from these surveys now make it possible to analyze and integrate the body size requirements of all of the U. S. Armed Forces on a standard basis. The comparison and correlation of anthropometric data on U. S. Army, Navy, and Air Force pilots is of particular interest and importance in the formulation of design criteria for U. S. military aircraft.

The new U. S. anthropometric data of 1966 also permit an assessment of trends in body size through analysis and comparison of similar data dating from World War I and World War II. Thus the examination of data collected over a period of some 50 years will form the basis for generalization and prediction of body size requirements for future aircraft design.

Anthropometric surveys have been conducted on military populations in several other countries in recent years. Among others, data are now available from Turkey, Greece, Italy, Japan, Thailand, Korea, and several Latin American countries, for example. The surveys of Turkey, Greece, and Italy were carried out for NATO under the sponsorship of AGARD.

The utilization and application of anthropometric data in engineering design is a complex area of technical specialization. However, some general comments or observations may be pertinent here. Requirements for anthropometric data cover an extremely wide range, from very simple to extremely complex. A designer may need advice on a small detail where the value of one measurement on the human body may suffice. The engineering design of an advanced weapons system may, on the other hand, require the statistical analysis, correlation, and integration of many body measurements.

Another important factor in the utilization of anthropometric data is that of communication between the researcher or the anthropologist and the user of the data or the design engineer. The anthropologist must have some knowledge of the design problems which involve human body size in order to provide the data required. The design engineer, on the other hand, should have some appreciation of the range of variation in body size in the human population in order to accommodate the human operator. Needless to say, it is of paramount importance that the anthropometric data made available to those who need it must be in a readily usable and understandable form. In other words, the anthropologist and the engineer must communicate with each other.

Change and progress are necessary in anthropometry, as in any other scientific or technical field. Traditionally, the human body has been measured in a few standard poses, using standard measurements and standard instruments. For some years it was felt that the resulting data from essentially rigid or static measurements were sufficient. These data were usually presented in the form of a few statistical values such as the mean, standard deviation, and perhaps some percentile values.

With changes in the state-of-the-art, it is now evident that the traditional techniques used in the collection, analysis and presentation of anthropometric data are no longer adequate. Many engineers are finding that problems in design engineering cannot be solved with the use of traditional anthropometric data presented in conventional form.

This situation is particularly true with respect to cockpit design. An important consideration in cockpit geometry is the provision for adjustability in the pilot's seat. The seat must be adjustable to accommodate a range of body sizes. However, the adjustability involves not only sitting height or eye height, but also several other body dimensions such as arm and leg lengths. Thus the inter-relationship or degree of correlation among several body dimensions must be examined.

It may be concluded, therefore, that new techniques of measurement, and particularly new methods of presentation of anthropometric data are required for progress to be made in cockpit design. More emphasis is now required on functional or dynamic measurements of the seated operator, in addition to the traditional static measurements of the rigidly posed subject.

GROUND AREAS VISIBLE FROM THE AIRCRAFT COCKPIT

EYE POSITION: A METHOD OF EVALUATION

by K. W. Kennedy, Anthropology Branch, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio, U.S.A.

Purpose

The purpose of this research was to develop a realistic and objective method for comparing aircraft in terms of the ground areas visible from their cockpits.

Method

The method consists of calculating the area of the earth's surface visible from the pilot's eye position, within a radius of 3000 feet (914 meters) and of 18,000 feet (5486 meters). The ground area visible, expressed as a percentage, may be regarded as an index of the visibility from the cockpit.

To obtain our basic data we used the Binocular Cockpit Visibility Camera developed by T. M. Edwards at the Civil Aeronautics Administration Technical Development and Evaluation Center, Indianapolis, Indiana. This camera produces superimposed pictures from two lenses separated by the average interpupillary distance. The camera is located at the cockpit-design eye position and the photographs thus obtained show a panorama of what the pilot could see if he rotated his head from side to side. An example of such a photograph is found in figure 1.

A simplified line-drawing is made of the Cockpit Visibility Photograph. Such a drawing is found in figure 2. It contains the essential information from the photograph and is referred to as the Cockpit Visibility Record.

To our knowledge, most evaluations of vision from the cockpit have not been carried beyond examination of photographs taken with the Cockpit Visibility Camera or similar photographs or drawings. Such records may be adequate when examining vision into three-dimensional space, but not when precisely examining vision to a plane, such as the surface of the earth.

To illustrate that only part of the terrain beneath the aircraft is visible from the design-eye position, angular coordinates describing the outlines of obstacles to vision are projected to the ground. Through simple trigonometric analysis, the location of the points where these vectors "strike" the ground were calculated relative to ground "0", a point on the ground directly below the aircraft.

Once all necessary points are determined and plotted, it is possible to define the areas on the surface of the earth that are visually inaccessible from the cockpit-design eye position. We have called these plots Ground Visibility Plots. Examples are found in figures 3 and 4.

Using a compensating polar planimeter, we can measure the areas of the earth's surface visible from the eye position in the cockpit. These values are expressed as percentages of the total being considered. For instance, from the eye position in aircraft A, the pilot can see 45.7 percent of the land surface within a ground radius of 3000 feet (914 meters) and 65.3 percent within 18,000 feet (5486 meters). These indices are realistic and objective bases for evaluating aircraft in terms of the adequacy with which they permit visibility toward the ground.

Fig. 1 COCKPIT VISIBILITY PHOTOGRAPH

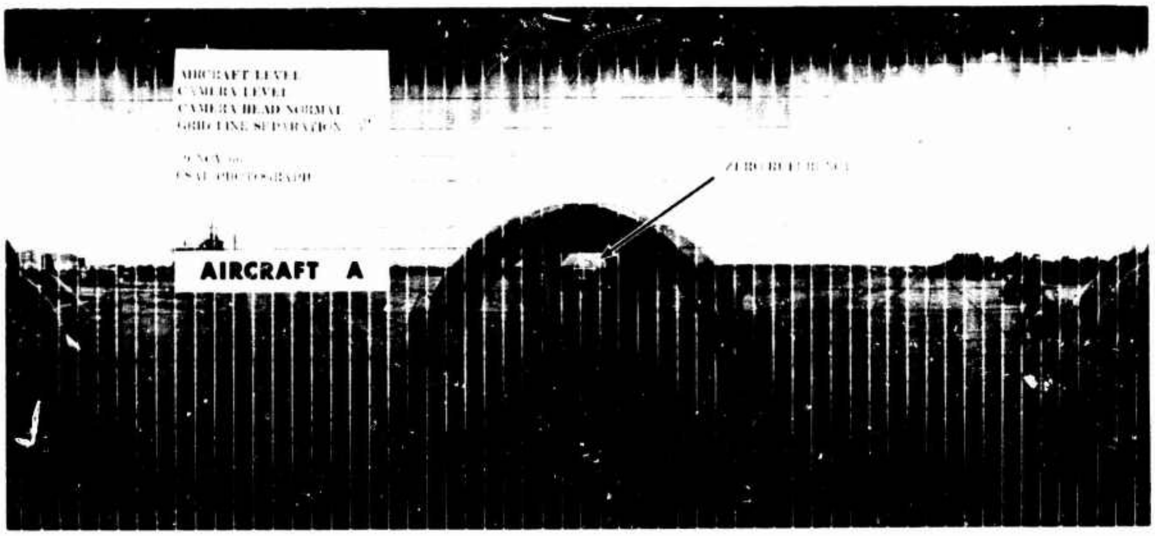
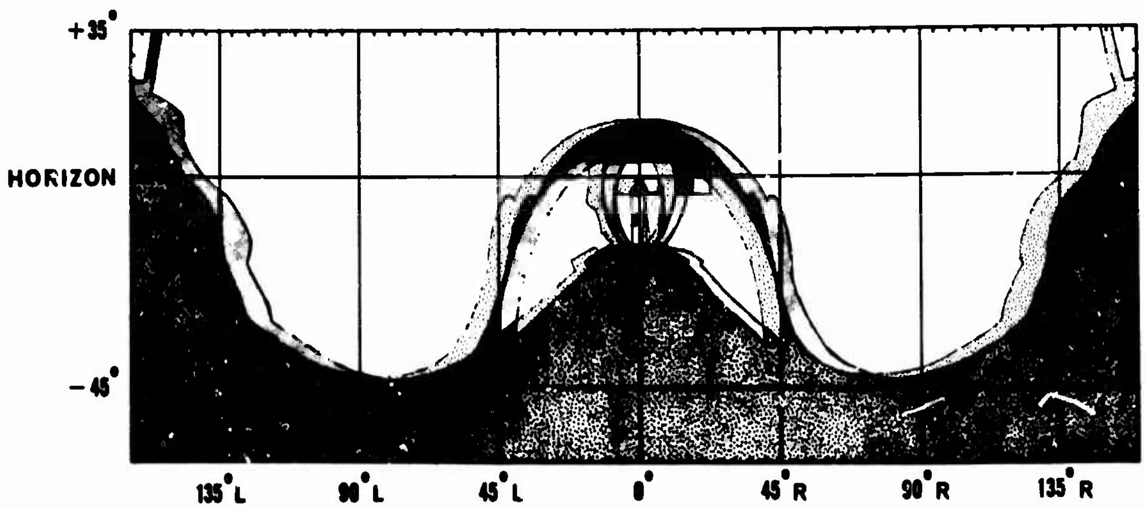


Fig. 2 COCKPIT VISIBILITY RECORD AIRCRAFT A

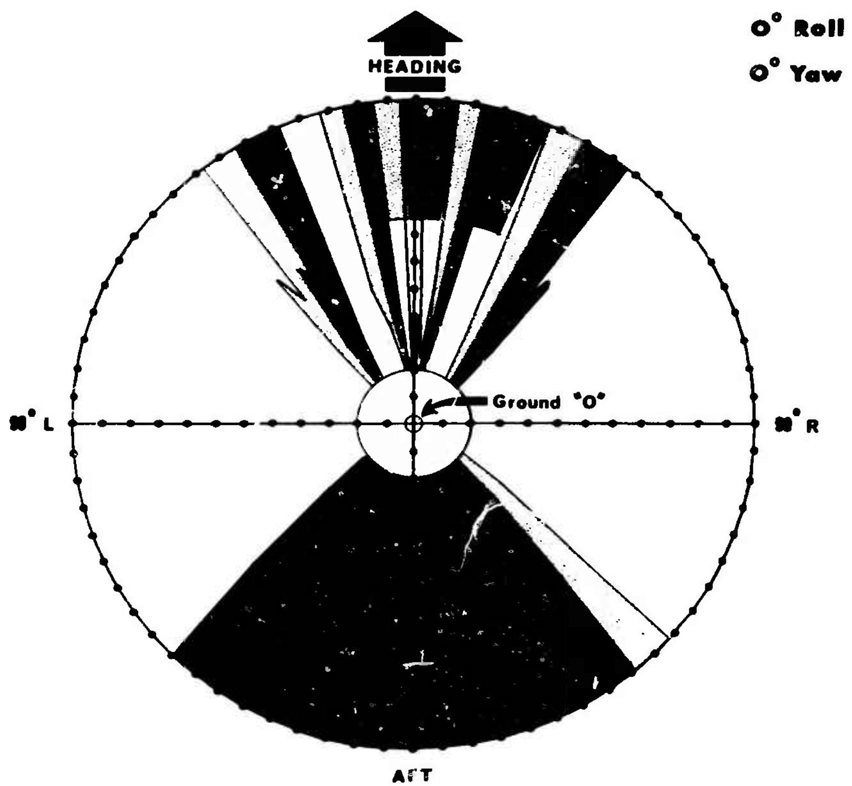
0° Pitch, 0° Roll, 0° Yaw



OBSTRUCTIONS TO VISION: Right Eye ▒, Left Eye ■, Both Eyes ■

Fig.3 GROUND VISIBILITY PLOT AIRCRAFT A

0° Pitch
0° Roll
0° Yaw

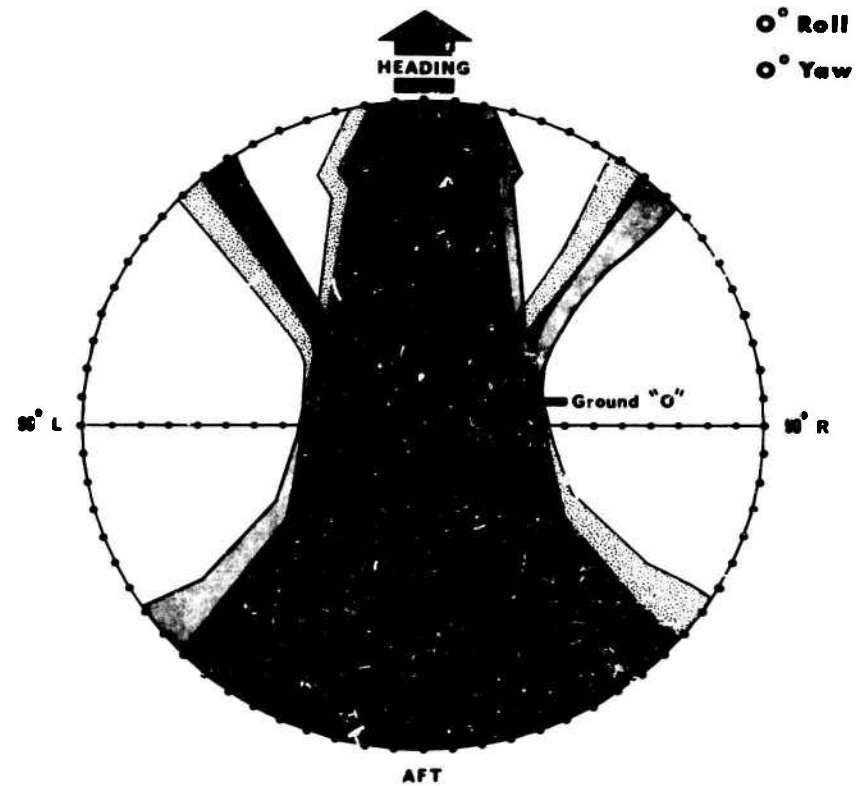


0 3 6 GROUND DISTANCE = NUMERAL X ALTITUDE OF AIRCRAFT

OBSTRUCTED TO VISION: Right Eye ▒, Left Eye ■, Both Eyes ■

Fig.4 GROUND VISIBILITY PLOT AIRCRAFT A

0° Pitch
0° Roll
0° Yaw



0 ½ 1 GROUND DISTANCE = NUMERAL X ALTITUDE OF AIRCRAFT

OBSTRUCTED TC VISION: Right Eye ▒, Left Eye ■, Both Eyes ■

PILOTS' ASSESSMENT OF THEIR COCKPIT ENVIRONMENT

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INTRODUCTION:

The pilots opinion of his cockpit environment may not reflect directly his working efficiency in that environment. Nevertheless the practising squadron or airline pilot is the only person experiencing the total flying environment. This means he has not only the complete display and control system available but also that he deals with this system in the wider environment of the demands of the flying task, standard operating procedures, meteorological change, instrument serviceability rates etc. In raw form the information is complex and difficult to analyse. Hence such feed back as the supporting scientists and designers do get is strongly conditioned by personal factors of the reporting pilots. In test flying such personal factors are supposedly minimised. How far this minimising of personal factors is achieved by use of standard vocabularies, rating scales and the like is a matter for empirical test. Laboratory studies tend to suffer, for practical and financial reasons, by using few subjects and a limited, if not a changed environment. Hence user pilot information is valuable. Problems remain as to how to get it and how best to utilise it.

The technique by which information is gained from pilots conditions the form of the information and so constrains its interpretation. Physiological measures are possible but information as to stress responses etc is very vague as to cause. Behavioural measures are often vague as well, or else they suffer from laboratory limitations. Verbal information has its own problems but has coverage and an apparent precision which other measures lack.

Studies at the RAF Institute of Aviation Medicine have ranged from the technique of the Semantic Differential (1 and 2) through studies of rating scales (3) to analysis of open ended questions with which this report is concerned.

Utilisation of information from a total environment is ultimately the problem of the system designer. System changes are usually expensive modifications. The time scale of such a feed back circuit, design, development, large scale use, user feed back, redesign is however in the order of ten years, by which time system concepts will have changed. Hence it is more likely that piecemeal applications will result and that the overall applications will be in more nebulous form such as development of a systems philosophy employing user information from past generations of aircraft among other sources of information.

As specific items are criticised however it would be quite possible to refine the argument by further questionnaires, not necessarily in open ended form, or it would be possible to go to the laboratory or the simulator to make comparative studies and to test hypotheses generated by quantified user information. Normally laboratory studies test hypotheses generated intuitively after a literature survey of studies generated similarly; with the bulk of the user pilot population and its experience excluded. The new data of this study offers a host of testable hypotheses which could also be further refined.

Test pilots also feel the lack of user opinion. They tend to report differently for different audiences and speak of trying to put themselves in the place of the hypothetical "standard squadron pilot" when writing acceptance reports and use different standards when reporting on research aircraft. The survey method itself has its own problems. They need not be discussed here, except to say that if user pilot information is found of value it is hoped that a higher response rate than the 8.5% perforce used here would be forthcoming. This study of the responses of airline pilots to open ended questions must be regarded as a preliminary investigation.

METHOD:

229 Civilian airline pilots responded to four open ended questions concerned with the design and positioning of the instruments, displays and controls of the aircraft they flew and to a more general question. (See Table 1). The survey covered nine different aircraft types.

Comments made by the pilots were classified according to the item mentioned. Table 2 exhibits the main grouping of criticisms. Groupings are included in this table if they were mentioned by more than an arbitrary ten per cent of the respondents. The main headings were sub-divided where the breakdown seemed of interest.

Non parametric tests were used to find the degree of agreement between the pilots as to the relative importance of the different questions, and to dispose of the suggestion that the different frequencies of response and thus the agreement was generated by the question order.

RESULTS:

The major response groupings appear in Table 2.

The nine groups of pilots grouped by aircraft type agree on the relative importance of the questions. Kendalls' concordance (W) is 0.54 ($p < .01$). It was not possible to randomise the order in which questions were answered in this survey study. Jonckheere's Trend Test indicates that there is no significant trend in frequency of response related to the order in which the questions were set out.

Table 2 indicates frequencies with which criticisms were made on the various topics. The main totals offer no surprises. Sub totals are of some interest. The Radio and Navigation Aids sub totals show that almost as much concern is expressed by pilots regarding control settings in these equipments as in reading the information generated by them. In some aircraft especially VHF frequency selectors are difficult to read and hard to use.

Comments on the flight systems are almost all 'environmental'. Standby artificial horizons frequently have their angle of bank pointer at the bottom of the display. Flight System indicators in use have them at the top. Cross referring between the instruments tends to confuse.

Items obscured by others, especially items obscured by the control column brings into question the doctrine of the big stick for the big aeroplane. Knowles (4) feels that the side-arm controller would not be widely acceptable to user pilots. In several cases in this study user pilots asked for smaller controller design to be considered.

DISCUSSION:

Generalisations from the results of this study must be tentative because of the low response rates involved.

However this study demonstrates that civil airline pilots are particularly concerned about certain areas of their cockpit environment and that they agree about these concerns despite the fact that they fly different types of aircraft. Data for separate aircraft are also of interest. Data from open ended questions can be reduced to quantifiable form, and hypotheses for testing either by similar survey methods, or in the laboratory can be derived.

Such laboratory tests would help interpretation of results since a tender-minded interpretation might be that criticisms are not really aimed at curing particular problems of information display, the major source of criticism, but are really complaints as to the quantity of information which the pilot has to cope with. Arguments against this hypothesis are that (a) it does not explain the agreement between the pilots which is taken here at its face value and (b) criticism of Radio and Navigation aids is in fact almost as much directed at 'setting' information as against the displayed information. The hypothesis could be tested by simulator experiments.

These results have been obtained from answers from a total flying environment. If modifications are undertaken they should also be assessed in that same environment. However intractable to analysis responses to open ended questionnaires are, it is important that information be sought from user pilots. It is true that extensive surveys of this nature are expensive to analyse and would cost time and effort to administer effectively. However if user pilots accept that their experience is being utilised they will be more likely to co-operate and to generate higher survey return rates. Standard procedures and computor programming could cut the time required for analysis.

SUMMARY:

Assessment by the user pilot is an important source of information as to the efficiency of aircraft display and control systems. Information of value to life scientists and engineers can be gained and reduced to quantitative form by use of open ended questions. In the study reported 229 civilian airline pilots responded to 5 open ended questions, about design and layout of their cockpit. They most often criticised their Radio and Navigation aids. Application of these results is discussed.

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Table 1.

PILOTS ASSESSMENT OF THEIR COCKPIT ENVIRONMENT.

The Questionnaire.

The questionnaire assured anonymity to the respondents, identified the aircraft type concerned and presented the following questions:-

1. On your present aircraft are there any instruments you find difficult to read and which in your opinion are confusing? If so what are they and why do you consider them inefficient?

2. Are there any faults in the layout of the instrument panels? If so what are they and how do you consider they should be rectified?

3. Are all your controls well designed and easy to operate? If not, please describe the faults.

4. Is the layout of controls satisfactory? If it is not how do you feel it could be improved.

5. Are there any other faults in your aircraft's cockpit design which you feel could be improved?

Table 2.

GROUPINGS OF COMMENTS COMMON TO >10% OF THE RESPONDENTS

Comment.	% of total Comments
Praise.	5.6
Radio and Navigation aids.	20.7
Instruments.	20.3
Items obscured.	15.3
Comfort and freedom of movement.	16.3
Stowage facilities.	8.7
Emergency procedures.	6.6
Flight systems.	6.4

SOME ASPECTS OF THE DISPLAY CONFIGURATION OF MODERN AIRCRAFT

by

H.Bollinger

To be published later

VTOL DISPLAYS AND CONTROLS FOR ALL-WEATHER FLIGHT[1]

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INTRODUCTION

Military and civilian use of VTOL aircraft has expanded considerably because of the unique ability of these craft to operate out of sites prohibitive to conventional aircraft. In military tactical situations, the rotary wing has particularly demonstrated its ability to perform a broad range of missions under adverse environmental conditions. As a result, the helicopter has become an important part of present operations and future plans in many military organizations. However, if this type of vehicle is to be a principal element in the air mobility concept, it is imperative that its operational capabilities be further expanded. This means that large formations of these aircraft must be able to perform in the same environmental conditions as the combatant organizations they support. Thus, systems must be developed which permit these missions under all-weather conditions.

The objective of the program discussed here was the analytic definition and laboratory demonstration of a representative system which would provide a capability for all-weather coordinated flight of helicopter formations in military applications.

METHOD

This study consisted of a series of iterative analyses and real-time man-in-the-loop simulations designed to synthesize an optimal system concept, in terms of pilot information processing and control capabilities, for the desired mission. The initial systems analysis developed a quantitative definition of a typical helicopter formation flight mission. The most appropriate formation configurations and maneuvering strategies were selected on the basis of a survey of prospective military users, and a representative mission profile was established which included a series of individual maneuvers and pilot tasks. Each segment of the mission was quantitatively described in terms of altitudes, headings, airspeeds and rates of these parameters. This profile is shown in Figure 1 and described in Table I.

The information and control requirements for each mission phase were functionally analyzed to determine the man/machine task allocation. Each man-assigned task was further examined to identify the specific information elements required for its accomplishment. These elements were used as the basis for configuring the alternative display formats. A further analysis identified and quantified the range of the sensed parameters and computational characteristics necessary to the assumed mission.

A series of preliminary man-in-the-loop simulations and computational error analyses bounded the area of feasibility for the desired system parameters. The candidate display configurations were optimized in terms of the information parameters presented and the quickening models employed. (Display quickening is a technique whereby first or higher-order derivative information is incorporated into the display of a control variable, thus providing the pilot with a degree of lead information.)

Based on the results of these preliminary simulations, three alternative display formats were selected for further study:

- A highly quickened plan position view showing the entire formation (Figure 2).
- A highly quickened forward-oblique pictorial display showing a perspective view of the lead aircraft (Figure 3).
- An abstract presentation of attitude, command velocity and attitude information on a vertical situation display. This particular format has been proposed as part of the Integrated Helicopter Avionics System (IHAS) (Figure 4).

Each of the above displays was supplemented with an array of conventional helicopter instruments which presented quantitative and qualitative flight control information.

[1]This paper is based on research supported by the Office of Naval Research under Contract N00014-66-C0362.

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To translate the results of laboratory studies into real-world system design requirements, it is necessary to consider the variation of the real-world input data and its effects throughout the rest of the system. To this end, a computational error analysis was performed to determine the sensitivity of the assumed system to sensing errors and computational rates and to bound the range for each of the parameters for further study. The results of this analysis indicated that system update rates ranging from 2 to 8 per second were most appropriate. Similarly, the analysis of system accuracies indicated that the assumed one-standard-deviation value of noise on the elevation and bearing measurements should encompass a range from .0014 radians to .042 radians. The analysis further indicated that system performance was insensitive to noise on the range measurement; thus the one-standard-deviation noise value for this parameter was maintained at 1.5 feet. A simple linear filter was assumed for the system. This filter was not varied during the formal experimentation.

Preliminary system analysis and previous experience with existing prototype systems indicated that the maintenance of close formation tolerances under adverse weather conditions is an extremely demanding task. Thus, the addition of an automatic flight control system was a logical choice to unburden the pilot and to assist in aircraft position control. An analysis determined the levels of automatic flight control augmentation appropriate to the formation flight mission. The selected flight control system configurations were:

- Free vehicle, no augmentation
- Yaw-axis stabilization
- Three-axis stabilization
- Altitude hold with three-axis stabilization
- Heading hold with three-axis stabilization
- Heading and altitude hold with three-axis stabilization

These six levels were tailored to the two helicopters studied -- the UH-1 and the AH-56. The analog representations of each level of augmentation were developed according to existing specifications.

All man-in-the-loop simulations employed a versatile hybrid computer-driven simulation facility at the Honeywell Inc. Systems & Research Division in Minneapolis, Minnesota. This fixed-base simulation facility permitted real-time performance measurements under varied experimental conditions. The analog portion of

the facility provided solutions to the vehicle equations of motion and the control authority calculations. The digital elements of the system performed the display calculations and controlled the total simulation. The pilot's simulated control station consisted of a collective stick, a cyclic stick and foot pedals; mounted in a configuration with the same dimensions of a typical helicopter station. The cyclic stick's centering position was fixed, and the stick forces assumed that a hydraulic boost was activated. All display formats were generated electronically and presented on a 17-inch cathode ray tube located approximately 30 inches from the subject. The general layout of these controls and displays is shown in Figure 5.

The subject pilot's task was to fly the mission as presented in Table I while minimizing formation position errors and avoiding collisions with other vehicles. Two of the subject pilots were aeronautical engineers and three were military pilots. All were rated helicopter pilots. The experimental plan was designed for systematic investigation of the previously discussed system variables, (namely, display formats, data rates, auto/pilot levels). Appropriate counter-balancing and randomizing techniques minimized any possible order effects. Two primary measures of performance were recorded and analyzed for each combination of the selected system variables: (1) measures of the precision with which the pilots maintained their assigned formation positions and (2) measures of control input magnitudes and frequencies. The position error data were used to describe the pilot's performance in terms of longitudinal, lateral, and vertical errors with respect to their assigned positions. The control input metric was the integral of the aircraft attitude rates in pitch and roll. In addition, collisions and control losses were recorded and used as comparative data.

RESULTS

The significant findings of this study were:

- Precise aircraft control can be achieved in the formation flight mode with little or no stability augmentation if the display is quickened with command signals dynamically equivalent to those signals essential for a stability augmentation flight control system, i.e., the command signals include terms which are only one or two time derivatives removed from the control stick output.

5

- The quickened plan-position display was the most satisfactory format from an overall systems viewpoint. This format appears to have the most potential for a formation flight system which would involve both manual and automatic flight modes.

- Inner- and outer-loop flight control system augmentation frees the pilot for such functions as communication and navigation which he could not otherwise perform.

- The effectiveness of augmenting the displayed elements is, in large part, dependent on position data rates and data accuracies. Parametric data on information rates and information accuracies (noise) have been established for various levels of flight path management precision. These data are critical for establishing design requirements and specifications for instrument flight rules (IFR), flight path management sensors, computers and displays.

TABLE I. MISSION PROFILE/PILOT REQUIREMENT

PHASE	PILOT REQUIREMENTS	TIME (SECONDS)
1. Rendezvous and Join-UP	Close from 2000 feet behind the leader to own position and decelerate to 70 knots	80
2. Acceleration at Straight and Level	Accelerate to 88 knots	30
3. Climb	Climb to 750 feet at 250 fpm	60
4. Right Turn	Turn to 060 degrees at 2 deg/sec	40*
5. Descent	Descend to 500 feet at 250 ft/min	60
6. Left Turn	Turn to 360 at 2 deg/sec	40*
7. Straight and Level	Maintain position	30
8. Deceleration	Decelerate to 70 knots	30

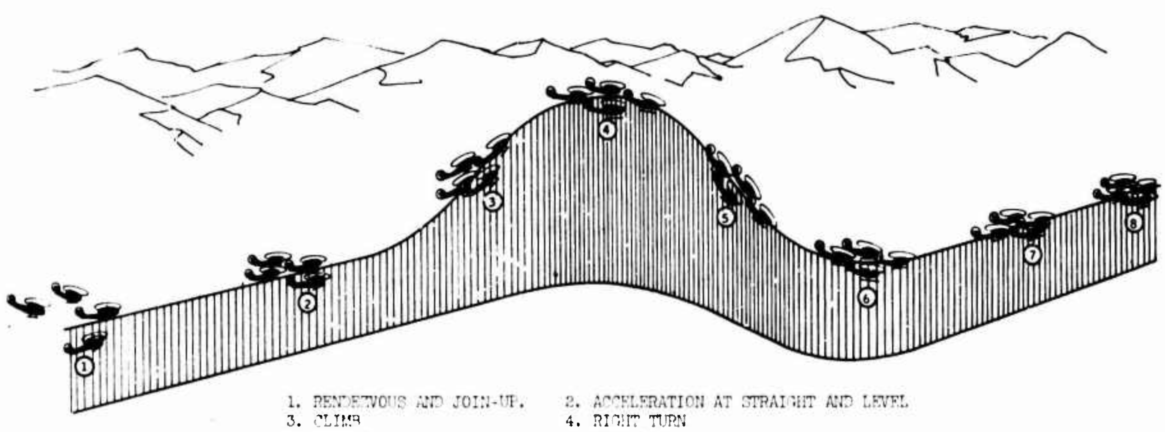
Total phase time: 6 minutes, 10 seconds

Minimum total of recovery time intervals: 1 minute, 10 seconds

Minimum mission duration: 7 minutes, 20 seconds

Initial Conditions	Leader	Follower (ΔX = -1293 ft, ΔY = -707 ft)
Heading	360 degrees	360 degrees
Altitude	500 feet	500 feet
Velocity	70 knots	88 knots

*A minimum of 10 additional seconds are required at the end of each turn to permit the follower to attain his position; thus the minimum turn time is 40 seconds rather than 30 seconds.



1. RENDEZVOUS AND JOIN-UP.
2. ACCELERATION AT STRAIGHT AND LEVEL
3. CLIMB
4. RIGHT TURN
5. DESCENT
6. LEFT TURN
7. STRAIGHT AND LEVEL
8. DECELERATION.

Fig.1 Mission profile

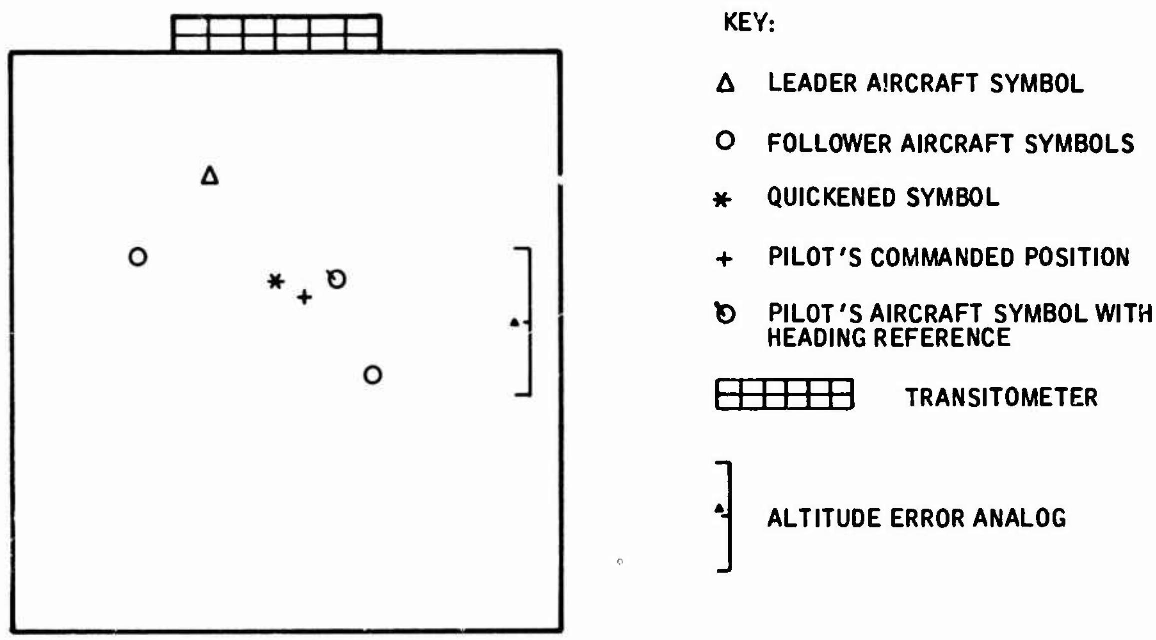


Fig.2 PPI display format

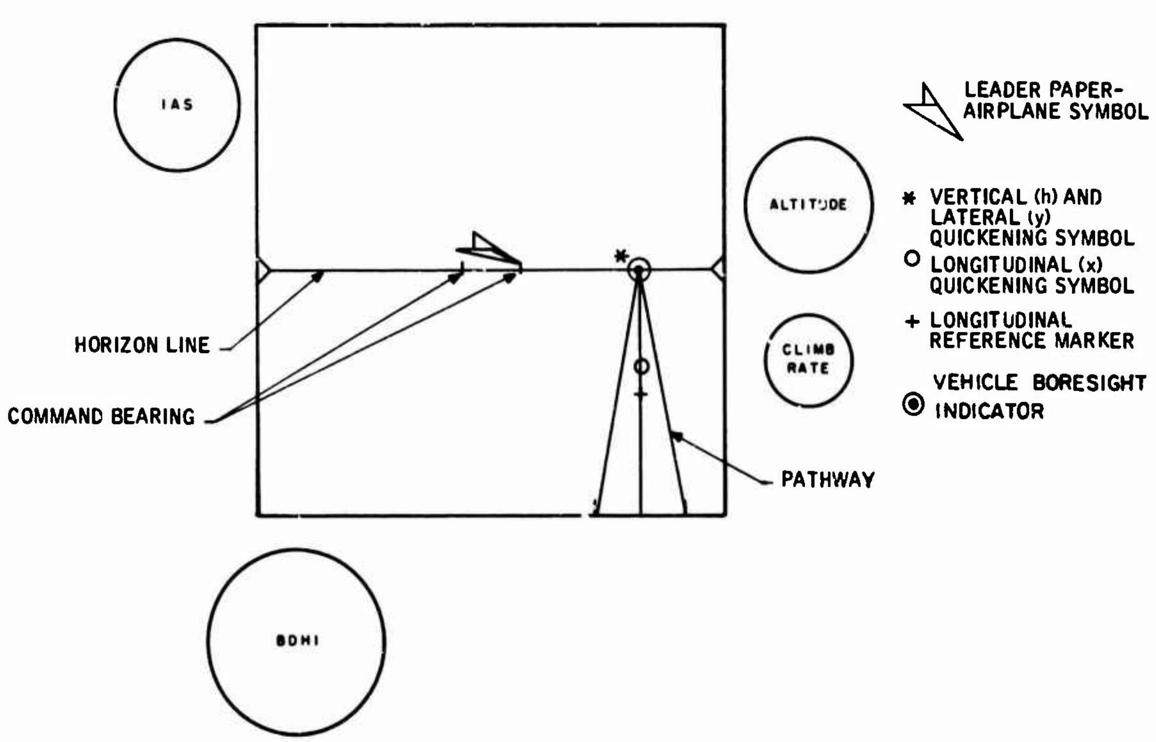


Fig.3 Oblique pictorial display

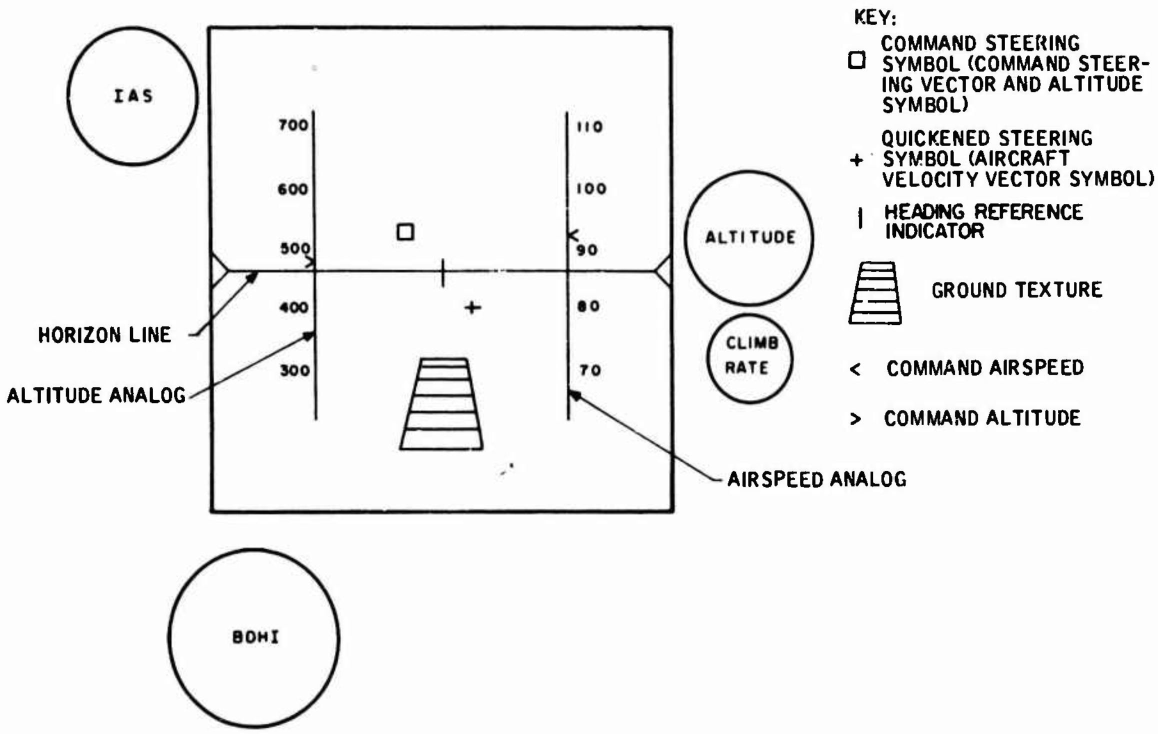


Fig.4 IHAS display format

Fig.5 Pilot's station

HEAD-UP DISPLAY OF APPROACH INFORMATION

by

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and

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1 INTRODUCTION

During an approach to landing the pilot wishes to know his position relative to the correct glide path and have some assistance in achieving a good approach. In conditions of restricted visibility this information must be obtained from aircraft instruments, but it is highly desirable that he is orientated with the outside world and that his attention is directed towards the touchdown point so that he can make contact with the emerging visual world and the runway at the earliest moment.

To make this possible it is necessary to present all essential flight information, normally obtained from cockpit instruments, at eye level and collimated so that it appears focussed in the outside world. The display should be centred on the touchdown point and provide 'position' information, and help the pilot to achieve and maintain the correct glide path by having a director facility. Aircraft pitch and roll information is also of prime importance and should be featured in the display. These facilities can be obtained using a head-up display in which the pilot views the outside world through a semi-silvered mirror and sees the collimated display, which may be generated in several ways, reflected in the mirror.

The use of the head up display as a means of providing flight information during the approach has in recent years, received a good deal of attention both in the U.K. and in other countries and various forms of display presentation have emerged.

The form of display,described here and known as the NAD display, was initially developed at the RAE for Naval aircraft, but it can be used equally well for airfield approaches, as has been demonstrated by extensive flying trials during the development of a fully engineered system. Although it contains features common to other displays, essential control information is presented in such a way as to attract the attention of the pilot to the landing area and to assist him to remain orientated with respect to the outside world.

2 DESIGN CONCEPTS

The system was designed specifically to display to the pilot all essential flight information for the approach using the minimum number of symbols.

In general, displays can be classified into three main groups:

(i) contact analogue displays which portray the ground in symbolic or pictorial form and have a one to one correspondence with the real world. However, displays of this form are difficult to generate and have a low information content.

(ii) superimposed displays in which the projected information is fixed relative to the aircraft. The collimated information appears superimposed on the outside world but its position depends on the direction in which the aircraft is pointing and therefore it is not directly associated with the ground which must increasingly be the pilot's frame of reference as the landing phase is reached.

(iii) integrated displays, which give similar information to superimposed displays but are orientated with respect to a point in the outside world, normally the touchdown point, so that the pilot's attention is directed at all times towards the landing area.

The NAD display is an integrated display. It contains a symbol which identifies the touchdown point. There is no relative motion between this symbol and the real world because the display is fully stabilised in ground axes. The display also contains a flight director facility, aircraft 'position' information, and roll and pitch attitude information. Only three basic symbols are required to

present the information. All the data inputs required for this system can be derived, with sufficient accuracy from equipments already in general use.

3 FORM AND OPERATION OF THE NAD DISPLAY

3.1 General

The complete display is shown in Fig 1. A split horizon bar is stabilised in roll, pitch and heading. Its mid point is the datum for 'position' information, the magnitude of which is indicated, as explained below, by the displacement of the target marker symbol from this datum. As shown, this symbol consists of a dot and an associated set of track lines.

The director symbol takes the form of an aiming circle shown in Fig 1 in some arbitrary position. This, in association with the target marker, provides the director facility and also shows aircraft pitch and roll attitude. The peripheral scales, which are fixed in aircraft axes, form a frame of reference and may display auxiliary information such as speed, height and heading.

3.2 'Position" Information

The manner in which 'position' information is derived and presented in the display is illustrated in Fig 2, where a typical approach situation is depicted separately in elevation and in azimuth. The aircraft is shown with angular position errors from the glide path of σ in azimuth and β in elevation as measured from the touchdown point. The magnitudes of these errors are available as data inputs in the aircraft. Thus the target marker symbol can be moved along and normal to the horizon bar through angles equal to σ and β , its displacement from the mid point of the horizon bar showing the aircraft's 'position'. The horizon bar, which is roll and pitch stabilised, is depressed from the horizontal through an angle γ equal to the glide slope. As mentioned previously it is also heading stabilised on the runway bearing. In all senses stabilisation is on a one to one basis.

It follows from Fig 2a that the pilot will see the horizon bar along the plane ON parallel to the correct glide path AP, since it is deflected through the glide path angle γ below the horizon. The target marker is deflected through the elevation angle β and will lie along the line OP. Similarly, (See Fig 2b) the mid point of the horizon bar lies along the line ON where ON is parallel to the centre-line AP. The target marker, since it is deflected through the azimuth error angle σ, will lie on the line OP passing through the touchdown point P. Hence it follows that whatever the position of the aircraft, the target marker will be seen, by the pilot, to be coincident with, or near to, the touchdown point depending on data input accuracies.

The geometry of the NAD display is such that a line through the target marker to a point γ degrees above the mid point of the split horizon bar will overlie the correct landing line for, as previously stated, the centre of the roll bar is stabilised on a heading parallel to the runway. Track lines parallel to the horizon are centred on this line below the target marker such that the ratio of the displacements between the horizon and each of these symbols (track bars and target marker) remains constant. Hence the track lines contract nearer to the target marker when the aircraft is low and expand further away when the aircraft is high, thus giving a perspective effect comparable with the Calvert's lighting pattern. It should be noted that this is not normally the case in other displays using similar track lines.

3.3 Flight Director

The flight director control laws are satisfied when the aiming marker is coincident with the target, and further the aircraft is on the glide path when the target marker - and also the aiming circle if the director laws are being satisfied - is coincident with the centre of the horizon bar. The control laws associated with this flight director can be compounded from various data generated or available in the aircraft.

For illustrative purposes, consider the simple control laws for the elevation and azimuth planes, as follows:-

$$\theta_D - K_3\beta = 0 \qquad (1)$$

$$\phi_D + K_1'(\psi - \nabla) - K_2\sigma = 0 \qquad (2)$$

Where θ_D = demanded increase in pitch attitude, relative to the datum attitude,

β = angular position of the aircraft below the glide path as measured from the touchdown point,

ϕ_D = demanded bank angle (position to starboard),

ψ = heading error of the aircraft to starboard of the glide path centre line,

∇ = drift angle (position to port)

σ = angular position of the aircraft to port of the runway centre line as measured from the touchdown point,

and K_1, K_2 and K_3 are constants.

These equations can be rewritten as:-

$$\frac{\theta_D}{K_3} = \beta \qquad (3)$$

$$\frac{\phi_D}{K_2} + \frac{K_1}{K_2} (\psi - \nabla) = \sigma \qquad (4)$$

If the displacements of the aiming marker δ_1 and δ_2 (See Fig 2) from the centre of the horizon bar are made equal to the left hand side of equations 3 and 4 respectively, then the aiming circle will appear in the display coincident with the target marker and the control laws will be fully satisfied. More complex control laws, especially in the azimuth plane can be used and are in fact highly desirable in many cases to compensate for errors which would result from using these simple control laws caused by the effects of variable crosswind, headwind, sideslip, changes in aircraft landing weight etc.

Complex laws may use, in addition to the terms already mentioned, inputs of beam rate, pitch rate, integral of heading, incidence, etc.

In any integrated display the heading and pitch stabilisation must be limited so that it always remains within the field of view, and this is so in the NAD display. Under such circumstances the system becomes somewhat degraded but will still function in the correct sense. 'Position' director, roll and pitch attitude information will be correct. However, the target marker will no longer lie on the touchdown point as this is now outside the field of view of the display. It is however still as <u>near as possible</u> to the touchdown point and still indicates the general direction in which to look.

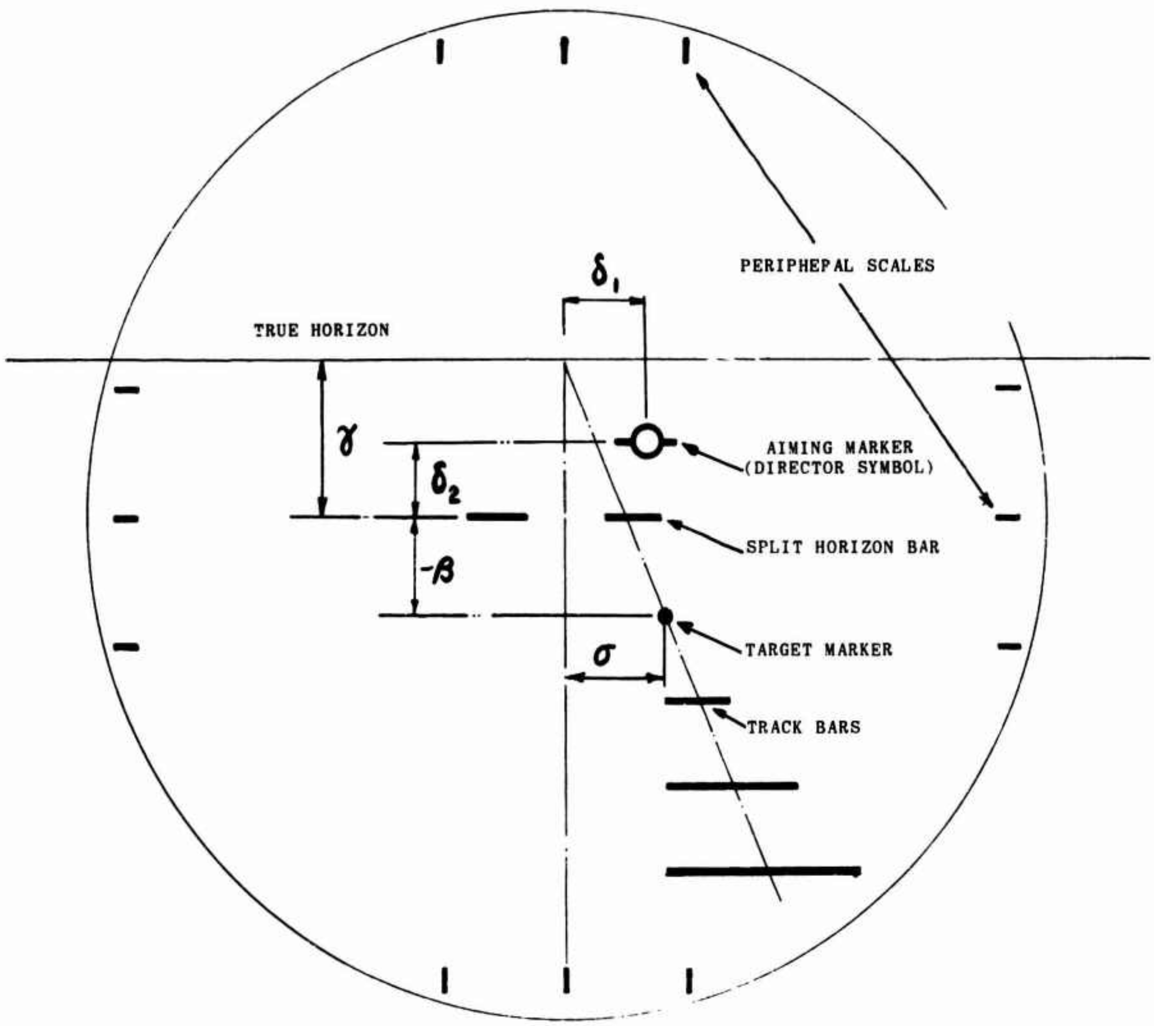
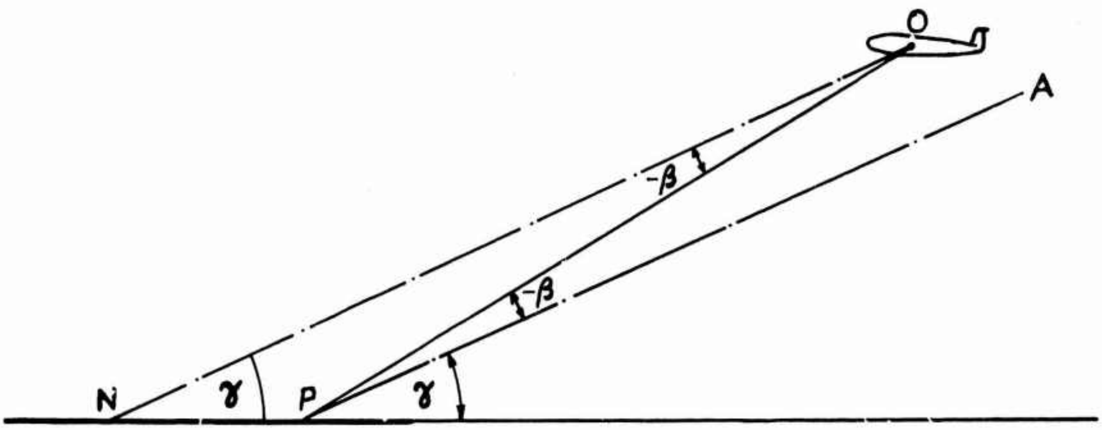
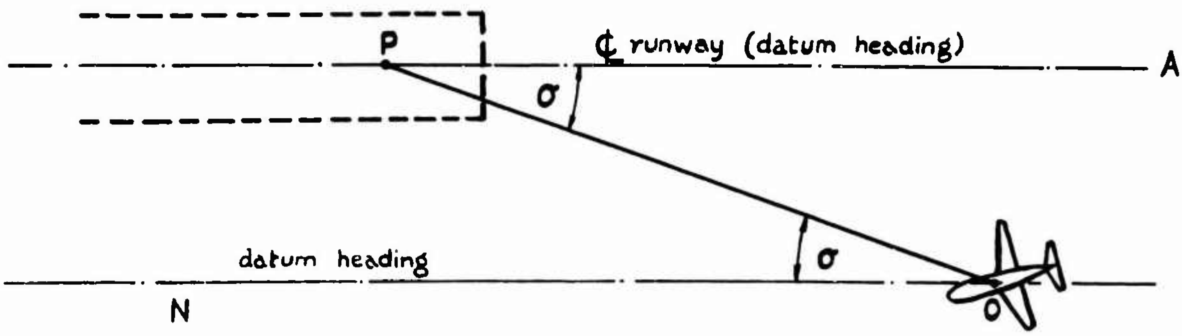


FIG.1 THE N.A.D. DISPLAY



a ELEVATION



b AZIMUTH

FIG. 2 DISPLAY GEOMETRY

Numeric Displays for dynamic information presentation

by

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The purpose of any display is to present information. In order to perform this function effectively it is necessary to ensure that the display employed possesses certain important design qualities; for example, lack of ambiguity, and is capable of presenting information in the form required by the operator in order to function effectively in the task situation. This paper considers the value of displaying information not in the form of the position of a pointer on a dial, but in direct numeric terms. One argument for this form of display in that at times the operator requires precise information about a perameter and in that situation he will think in terms of numbers. If a scale and pointer display is employed he will end up translating the position of the pointer into a numerical value in his brain, so why not present the information directly in numerical?

Recent programmes of research have investigated the use of numeric displays as methods of presenting time information, (1) and for replacing conventional scale and pointer displays on some machine tools (2,3). Other research has indicated that numeric displays can provide rate information and (4) that they can provide information allowing systems to be monitored effectively (5). Examining of the literature on numeric displays (6,7,8) led to the conclusion that they were considered to be good for presenting quantative information, were poor for providing qualitative information and were not acceptable in situations where there was dynamic information and some form of continuous control might be required. Persuing the literature further produced the conclusion that despite these recommendations very little experimental research had ever been undertaken to evaluate numerical displays under dynamic conditions.

The Institute has been concerned with research which has been directed towards examining the value of numeric displays as part of a closed loop tracking system. The experimental programme arose from the investigation of the likelihood of misreadings occurring on multi-pointer altimeters, and the potential of the counter-pointer altimeter as a means of presenting unambiguous height information (9). With the counter-pointer altimeter the assumption was made that in order to provide the necessary rate and trend information, required when height was being changed or maintained, it was necessary to provide a scale and pointer display to enhance the numerical indicator. It was however decided to attempt to test experimentally, the hypothesis that tracking was not satisfactory with a purely numeric display. The outcome of this experiment (10) was the indication that no significant difference in performance on a compensatory tracking task could be shown when using a purely numeric display, compared with using either a scale and pointer display, or a counter-pointer. This result was contrary to expectation and it was concluded that a possible explanation was that the numeric display was less efficient than the other displays, but that parity of performance had been obtained by an expenditure of an increased attentional effort on the part of the subjects when using the purely numeric display.

In order to investigate this hypothesis a second experiment was undertaken in which a subsidiary task was present in the experimental situation (11). The secondary task took the form of a light acknowledging task. If a light was not acknowledged in a given time it was recorded as a missed signal. It was argued that a measure of performance on the light acknowledging task would provide an indication of the variations in attentional effort demanded by the alternative visual displays.

Results obtained in this experiment showed that whilst performance on the compensatory tracking task remained unaffected by variations in the display employed, performance on the secondary task was significantly affected. Subjects failed to acknowledge twice as many lights when tracking with a purely numeric display as when tracking with the counter-pointer display. It was therefore concluded that the original hypothesis was substantiated and parity of performance with the numeric display had been achieved at the expense of increased effort on the part of the subjects.

The results obtained from the second experiment were supported in a third (12) which compared compensatory tracking using a numeric and a scale and pointer display when using an acceleration order control. Again a secondary task was employed, but in this case it took the form of a peripheral light signal which originated at either the left or right periphery at an angle of 45° to the centre line of sight and progressively stepped inwards at 10° intervals until cancelled by the subject. This experiment showed a significant decrement in the time off target when using the numeric display, a significant deterioration in performance with both displays when the peripheral light task was present, and in terms of the light task itself a slowing of response to the peripheral lights when the numeric display was in use.

A third experiment sought to examine performance when the experimental task was that of setting, e.g., changing from one commanded altitude to another (13). Setting performance was measured in terms of speed and accuracy of achieving a required value, and once again secondary task performance was measured using the two choice light acknowledging task. It was found that the presence of the additional task increased the time taken to achieve a successful setting, but that the increase was not significantly different between the two displays. The increase in setting time was contributed to by an increase in the errors which subjects made whilst undertaking the setting. Whilst the percentage of runs in which errors occurred was not significantly different between the two displays, there was a difference in the type of errors which were made. Sixty nine percent of those errors made on the numeric display resulted from the subject overshooting the required setting. In the case of the counter-pointer display, 62% of the errors resulted from the subject levelling out early before reaching the required setting.

From the above experiments it is concluded that, a purely numeric display can provide sufficient information to allow subjects to perform continuous tracking tasks. However it would appear that the attentional cost to the subject using this form of display can at times be great, and will show itself in a deterioration in the subjects' ability to perform other tasks at the same time as the task involving the numeric display.

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THE APPLICATION OF CORRELATION TECHNIQUES TO GROUND BASED AIDS IN THE TERMINAL AREA

by

J. Benjamin, Royal Aircraft Establishment

The paper outlines R.A.E. research which is aimed principally at improving the performance of I.L.S. and studying its role in future terminal area operations. Although this subject is fundamentally concerned with ground based systems it is evident that their design, operational performance and associated shortcomings have an important influence on the cockpit environment and Pilot work load. Ideally one should ensure that any ground derived information supplied during approach and landing is appropriate to each phase of the operation, is consistently accurate and of the required reliability and integrity.

At the present time the International trend is towards automatic flight control leading to a Blind Landing capability and several aircraft systems have been designed to operate with a failure risk less than 10^{-7}. To some extent the performance of the complementary ground based equipment is lagging and this defect will grow in importance as automation in the air increases. The future of I.L.S. is therefore a topical subject and a logical approach to the problem is outlined in this paper, which emphasises the long term need for flexibility, to give the equipment manufacturer the ability to design in the required amount of integrity appropriate to the operation.

The present status of I.L.S. is reviewed and it is emphasised that in spite of certain fundamental shortcomings the overall performance is good and its International implementation, regulated by I.C.A.O., has resulted in an expanding investment with associated technological support. From this it follows that any future replacement system must be shown to offer all the improvements sought without introducing new problems or operational penalties. It is therefore suggested that there is a strong argument for a truly compatible and evolutionary solution to the medium and long term objectives.

The way these aims may be achieved using hyperbolic phase fields and correlation detection is outlined and the design principles of the system are illustrated by description of the basic localiser. It is shown that true compatibility can be designed for without introducing undesirable restrictions or degrading performance. In these correlation guidance systems the aircraft, because of its position and speed, acts as a range and velocity gate so that wide band modulations can be exploited to achieve time and frequency discrimination. The use of microwaves enables the polar diagrams to be matched to the guidance needs and the hyperbolic geometry allows the approach and landing phases to be separately optimised. In addition the positioning of the transmitters in a hyperbolic configuration is flexible and avoids the many undesirable features arising from the need to site a conventional localiser in line with the runway centreline.

The features of this new I.L.S. which affect the Pilot are discussed. There is the possibility of providing true redundancy in the equipment and the transmission path coupled with the improved performance to give integrity related to the 10^{-7} accident risk. Multiplicative systems can also increase the number of channels available on the ground without increasing the switching problem in the aircraft and this feature can be extended to "time gated" communications to reduce the need for en route channel switching.

The problems associated with Pilot Monitoring during automatic approach and landing could be eased by improving the marker beacons so that they generate gates defining lateral displacement and height as well as range. The data link, integrated into the correlation I.L.S., can be used to automatically display ground derived information such as meteorology, airfield state, distance to go etc. so reducing the load on voice communications. In addition to these factors there are the problems likely to arise from new terminal area developments. There is already a need at some airfields for a curved approach I.L.S. - to avoid obstructions - and this feature may become necessary to separate traffic in approach and take off to and from parallel runways. Coupled with this will be a requirement for a generally improved navigational accuracy within the terminal area and this could be met by the use of upward looking I.L.S. systems.

Finally some problems common to all microwave systems are mentioned to show that "a move to microwaves" is not in itself a panacea for all the real or imagined troubles of V.H.F. I.L.S.

HEAD - UP DISPLAY SYMBOLOGY

by

Ir.F.E. Douwes Dekker

1 Introduction

Head-up displays are available now to be installed in civil and military aircraft for operational use.

So far, however, direct application of such systems is not envisaged, except for the rôle of a sophisticated gunsight, including a modern flight director.

The apparent reluctance to incorporate a head-up display in a modern cockpit is not only based on the relatively high price but also on the absence of sufficient evidence of the benefit to be expected.

Manual blind landings have been demonstrated at various research centers in the U.S., the U.K. and France. These systems comprised head-down or head-up director displays and different types of automatic assistance such as speedhold and kick-off drift. It has been clearly shown that the quality of automatic landings can be matched by manual landings, provided that appropriate information is presented to the pilot.

2 Manual Blind Landing

It has been demonstrated, that manual blind landings, including roll-out to standstill, can be performed by relatively inexperienced pilots. This has been achieved by a carefully designed flight director, which is well matched to the aircraft's dynamics during approach and flare-out, and usually includes auto-trottle and automatic line-up prior to touch down.

Complete obedience to the head-up display flight director signals was required. This was best achieved with the windshield blanked out, to prevent the pilot from being disturbed by the outside-world.

This most curious "contradictio-in-terminis" of the use of a head-up display indicates that flight director signals, having no direct relationship with the visual cues, should not be superimposed on the outside-world. This is supported by the fact that similar piloting performance can be achieved with appropriate head-down flight director displays with similar sensitivity and dynamic characteristics.

It may be concluded, that a human pilot is able to take-over a main part of an automatic control loop of a fairly complex manoeuvre near the ground, without degrading the performance of the system, if appropriate flight director information is presented. Although much effort has been put into this development, it did not establish a basic feature of the use of a head-up display.

3 Instrument-to-Visual Transition

The original reason, why head-up displays became attractive, was the need for a smooth transition from instrument to visual flight near the decision height.

This need appeared to be related with category 1 and 2 weather minima and specific cockpit procedures. Further growth of experience and lowering of operational weather minima revealed however, that the transition problem seemed to disappear due to the practical objection to take over visually at a very late stage of the approach.

Instead of that, further emphasis was laid on the satisfactory monitoring of the automatic landing, or on the continuation of manual instrument flying regardless of actual forward visibility.

However, outside visual cues, when available, should obviously be used to check and confirm correct functioning of the complete control system, including the human pilot, at the final stages of the flare-and roll-out. In order to avoid confusion, an immediate relationship between natural and artificial signals should exist.

This leads to the conclusion that head-up displays remain worthwhile, provided that the above objectives may be reached, i.e. satisfactory monitoring of easily flyable symbols through direct comparison with the outside-world.

These objectives are of even greater importance for the military rôle of low-altitude high speed flight in marginal weather conditions. In this case, temporary visibility reductions should not lead to higher values of ground-clearance. This means that continuous monitoring of the correct functioning of the head-up display should be achieved, in order to allow continuous use of it's symbols as basic flight control parameters in most weather conditions.

4 Integration

In the past, the word integration was used to indicate that several conventional flight parameters were presented all together in one or two main indicators, including two flight director signals.

This caused a substantial reduction of the scanning area of the pilot's eyes with his head down. The need for continuous monitoring of this limited area of flight information was then satisfied by the introduction of in-line or comparator warning systems on the correct output of the various transducers.

The flight director principle has often failed to impress the aviators, because the indications seem to restrict the exertion of human flight control unnecessarily to one arbitrary flight path, for instance in any capture mode. The benefit was to be found only in reducing the pilot's workload by presenting anticipatory information in certain phases of flight, like the final stage of an ILS-approach.

With the increasing reliability of automatic control systems, it seems obvious to limit the use of this type of programmed information to the auto-pilot.

On the other hand, there is little progress to be noted in the field of real integration of flight control parameters, i.e. to provide the pilot with new parameters, which describe essentially the dynamic situation, he lives in continuously.

Untill to-day, the flight information presented to the pilot consists mainly of basic academic parameters defining his actual flight condition : 3 position co-ordinates, 3 attitude angles, side-force and rate-of-change of heading and altitude.

During many hours of stringent concentration "under the hood", the pilots have learned to cope with the situation and to find their way through the skys "on instruments". They had to compute and control their flight path, within certain limits, becoming gradually narrower with increasing speed and lower altitudes "on instruments".

To-day there seems to be no reason anymore to deprive the pilot of actual vectorial flight path information in relation with aims and limits of his flight path as imposed by the outside-world.

This should be the basis of real integration of flight control information in a modern sense. An immediate consequence of this objective is of course the feasibility of direct flight path control.

5 Flight Path Vector

Present head-up displays provide visual information to the pilot, which is usually collimated to infinity. This eliminates the need to focus when observing instrumental flight information and outside visual cues at the same time. However, the most important feature of this type of presentation is the possibility to provide three-dimensional vectorial information.

In all phases of visual flight near the ground, the exertion of visual flight control is based on vectorial information through the pilot's eyes, i.e. the flight path vector represented by the source of all streamers on the retina of the pilot's eyes, in relation to the direction of view of various fixed points of the outside-world.

By providing both types of basic visual information, flight path vector and fixed points in a head-up display, the possibility arises to improve the ease and safety of visual flight control, to maintain the same piloting technique regardless of forward visibility, and to monitor the displayed signals when the outside-world is visible.

This starting-point for the design of head-up display symbology is valid for all phases of flight near the ground. The realization of these ideas however, requires an angular accuracy of the displayed vectorial information which is compatible with the sensitivity of the human eye, i.e. in the order of .1 degree.

The accurate computation of the actual direction of the flight path vector and various fixed points on the earth surface require sophisticated inertial, radar and pressure sensing equipment dependent on the flight mode envisaged.

6 Display Symbology

Figures 1 and 2 illustrate the basic lay-out of head-up display symbology for civil and military use, as a primary flight instrument for all flight conditions below 1000 ft AGL.

The 1 to 1 relationship with the outside-world is an essential feature of this symbology. The longitudinal axis of the aircraft is represented only by the framework of the cockpit window or combining glass.

Figures 3 and 4 show examples of typical views through a head-up display, within a conical field of view of 12 degrees in the direction of flight. It should be noted, that practically all the information of interest for flight control near the ground may be found within this 12 degree cone, for both civil and military application.

Certain automatic sub-systems are supposed to be used eventually such as aircraft stabilisation, kick-off drift or heading hold. Sophisticated terrain-follow sensors are supposed to be available, to indicate the top of the nearest obstacle which determines the minimum flight path angle within a given flight envelope.

7 Application

With some imagination several types of display symbology can be designed. Many others may have come to similar conclusions with regard to the basics of head-up displays, notably at the "Centre d'Essais en Vol", the RAE "Blind Landing Experimental Unit", or the USAF "Flight Dynamics Laboratory".

However, the proof of the pudding is in the eating. Therefore only experimental evidence from flight operational testing can satisfy the most critical observer.

Development work in this field in the Netherlands has been limited so far to preliminary simulator investigation of the flight path vector concept, and design studies of a head-up display system for research purposes.

Flight testing is planned to start in the third quarter of 1969 with a Beechcraft Queen Air-80 laboratory aircraft of the (Netherlands) National Aerospace Laboratory NLR. This aircraft is or will be equipped with a Specto head-up display, a Litton inertial attitude and acceleration sensor, a Smith's air data computer, a Sperry autopilot, an STC (or Bendix) radio-altimeter and NLR interface equipment.

The immediate objectives of these flight tests are to gain experience in the generation of accurate vectorial information, the use of the flight path vector as a primary flight parameter, including some form of quickening or damping, and the choice of symbols fixed to the outside-world.

This experimental study is sponsored by the Research Branch of the Directorate Material Air of the Royal Netherlands Air Force, and is related with current studies on cockpit lay-out of post - 1975 combat aircraft.

Further experiments with this head-up display may therefore be expected to be carried out in the Hawker Hunter T MK 7 laboratory aircraft of the NLR.

8 Note

This paper reflects the personal thoughts of the author, which do not necessarily coincide with those of the NLR or the RNLAF.

The idea's outlined above are of course influenced by other work in this field in other research centers and industries, and are probably not original. They may, however, add to underline an interesting trend in the development of flight control through the proper use of a head-up display.

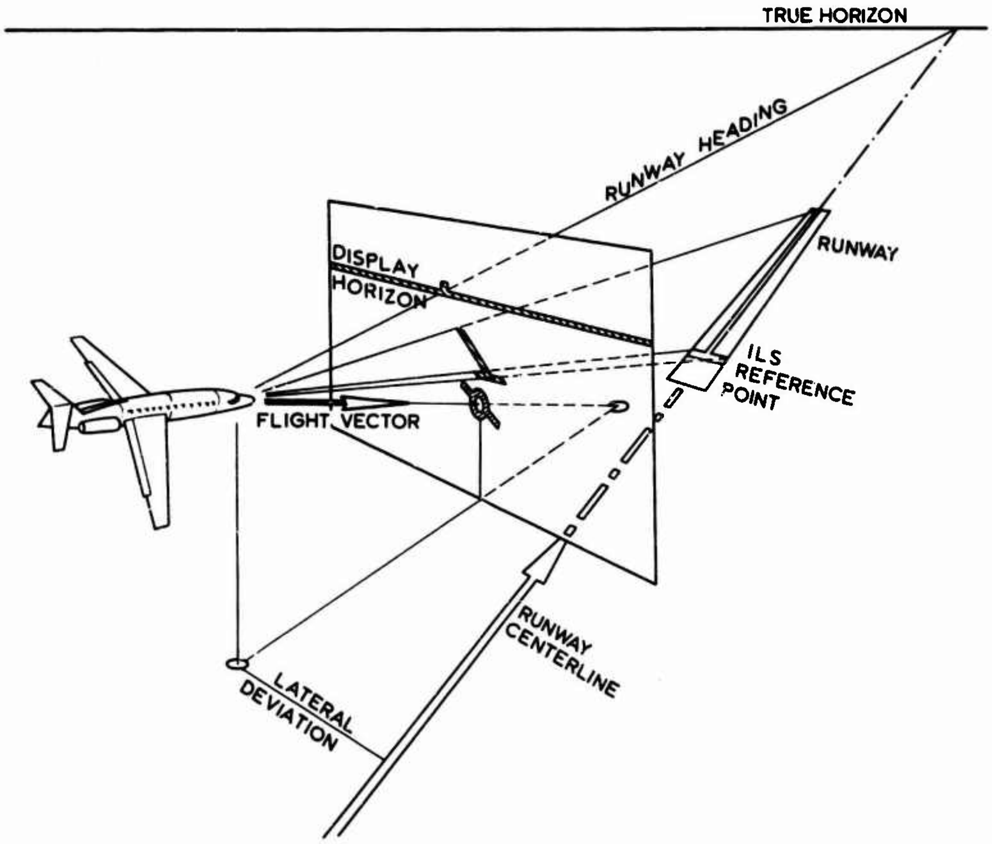

FIG.1 CIVIL HEAD-UP DISPLAY DEFINITION.

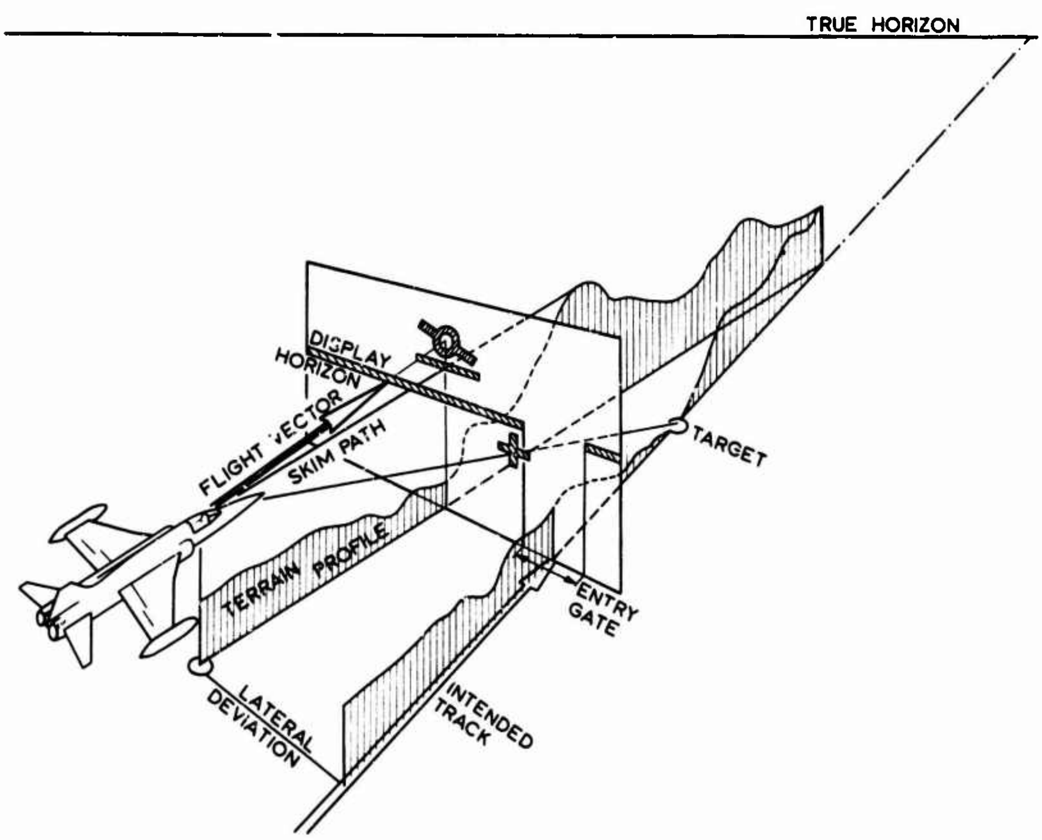

FIG.2 MILITARY HEAD-UP DISPLAY DEFINITION.

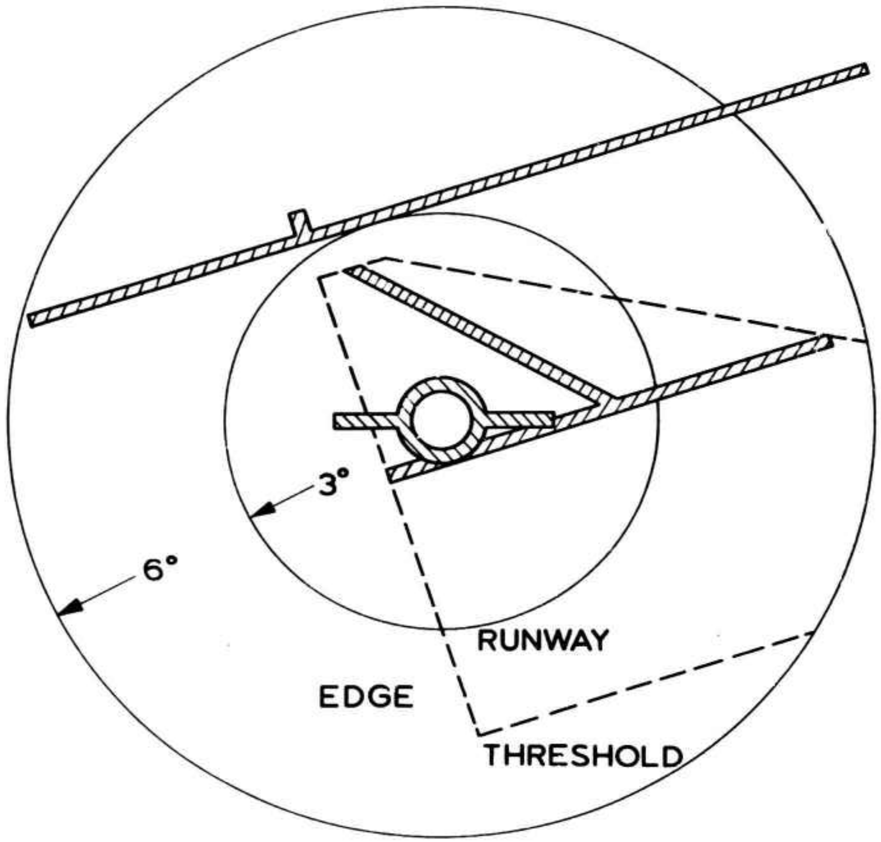

FIG. 3 TYPICAL OUTSIDE VIEW THROUGH CIVIL HEAD-UP DISPLAY.

35 m EYE - HEIGHT;
31 m LEFT OF CENTERLINE;
268 m FROM THRESHOLD;
20° RIGHT BANK.

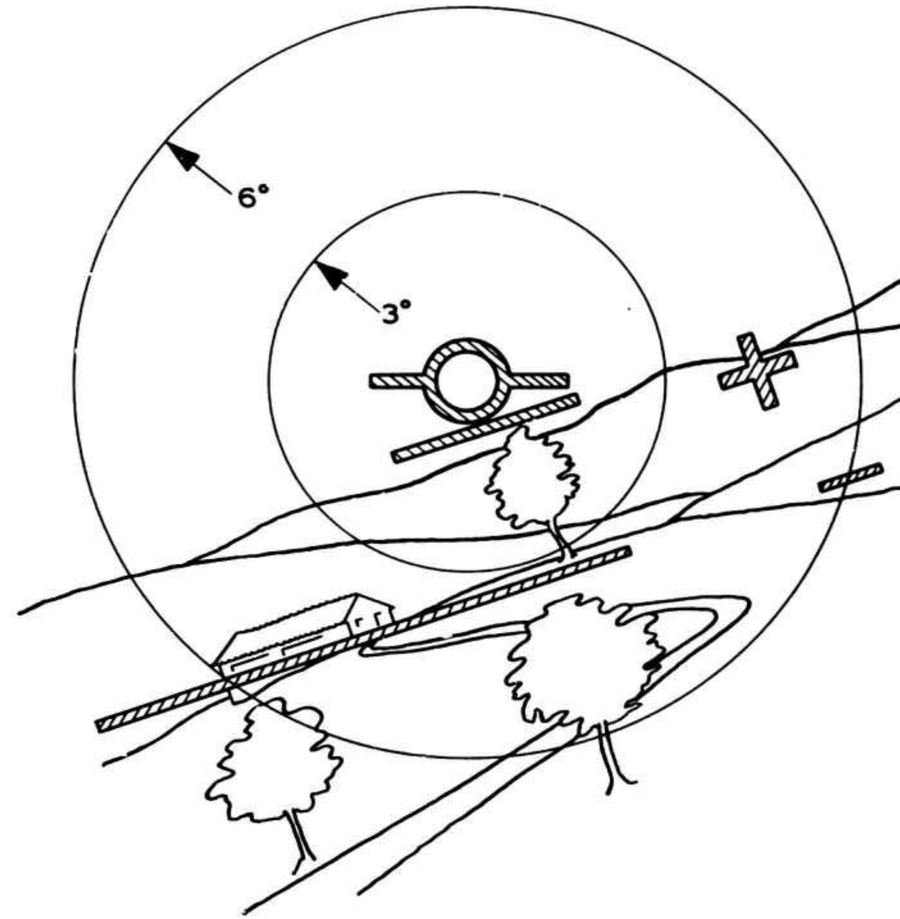

FIG. 4 TYPICAL OUTSIDE VIEW THROUGH MILITARY HEAD-UP DISPLAY.

EYE-HEIGHT 60m ABOVE TERRAIN, 140m BELOW TARGET, AT 4000m DISTANCE;
20° RIGHT BANK.

" ELABORATION ET PRESENTATION D'INFORMATIONS D'AIDE A L'ATTERRISSAGE "

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Dans le cadre général des études actuellement faites pour aider le pilote d'un avion moderne à l'atterrissage par mauvaise visibilité, l'exposé suivant esquisse une tentative de solution :

- par l'élaboration d'ordres de pilotage
- par la présentation de ces ordres et d'informations complémentaires sous une forme directement utilisable pour le pilote.

Cette solution, applicable plus particulièrement aux avions militaires équipés de radar d'interception et aux avions civils équipés de radar météorologique ayant au moins deux axes de liberté complété par des circuits de poursuite, élabore des informations permettant au pilote de contrôler l'atterrissage et même en l'absence de visibilité ou de guidage sol, d'assurer correctement le retour au sol. Dans ce cas l'ensemble proposé correspond à un matériel classé catégorie II ou catégorie III A.

I - ELABORATION D'ORDRES DE PILOTAGE

A partir des données :

- distance de l'avion à l'entrée de piste D.
- relèvement de l'entrée de piste vu de l'avion G.
- Site absolu de l'entrée de piste vu de l'avion S.
- Altitude de l'avion par rapport au sol Z,

qui peuvent être fournies par un radar de bord en poursuite sur une balise située à l'entrée de piste en liaison avec la centrale de cap et de verticale et par une sonde radioélectrique.
Et avec les affichages suivants effectués par le pilote :

- cap de la piste P
- taux de descente souhaité θ_o

Il est possible d'élaborer des ordres que le pilote doit maintenir à zéro.

Ces ordres sont de la forme (figure 1) :

. Dans le plan vertical

$$\gamma_z = Az\ (S .\ \theta o) + Bz\ (\theta - \theta o)$$

avec θ = pente du vecteur vitesse avion.

. Dans le plan horizontal

$$\gamma_y = Ay\ (G + C - P) + By\ (C - P)$$

avec C cap avion

et ou Ay Az By Bz sont des coefficients de gain.
Les termes après les coefficients A sont les erreurs de position du système, les termes après les coefficients B correspondent à un amortissement.

Des simulations, effectuées sur machine analogique dans le plan vertical, ont permis de définir la valeur des coefficients *Az* et *Bz* et d'apprécier les précisions nécessaires sur les différentes données et sur les affichages à effectuer.

Les résultats obtenus montrent qu'un tel système peut permettre la prise de terrain et l'atterrissage avec une bonne précision et une sécurité, qui pratiquement, sera d'autant plus grande que les ordres seront mieux présentés au pilote.

2 - PRESENTATION

Les présentations envisagées sont effectuées par un collinateur qui forme une image à l'infini à travers le pare brise. Ces images sont réalisées par des réticules lumineux mobiles mécaniquement.

2.1. Présentation synthétique des ordres sans référence extérieure (autre que le sol lui-même).

Dans ce cas deux formes de présentation sont possibles :

- soit des ordres en piqué-cabré et roulis sous forme d'un directeur de vol à maintenir sur la maquette de référence.

- soit des ordres en site et gisement sous la forme d'un point à maintenir au centre de la maquette de référence.

Ces types de présentation ont l'avantage d'une grande simplicité mais ont l'inconvénient d'obliger le pilote, lorsqu'il aperçoit le sol, à un effort d'adaptation pour assurer la transition ordres-sol.

2.2. Présentation synthétique des ordres avec référence extérieure. (figure 2).

Les ordres sont présentés par rapport à une référence fixe par rapport au sol :

La figuration projectée figure l'horizon et la position de la balise d'entrée de piste connue par ses coordonnées par rapport à l'avion.

Les ordres sont donnés dans un système d'axes vertical-horizontal centré sur la balise.

Le pilote doit manoeuvrer pour amener en permanence le directeur d'ordre sur l'image de la balise d'entrée de piste.

Le pilote possède ainsi une vision des références extérieures en même temps qu'il voit les ordres de pilotage.

Une amélioration de la présentation est de figurer à la place de la balise d'entrée de piste, une piste simulée en perspective qui se superpose pratiquement avec le dessin de la piste elle-même (variation de la grandeur en fonction de la distance). Ainsi les transitions : passage du pilotage aux ordres au pilotage par rapport au sol, se fait sans difficulté.

Un tel système, pratiquement indépendant de l'infrastructure sol, peut permettre une vérification permanente de la qualité de la trajectoire effectuée à partir d'informations données par des systèmes sol (I.L.S. par exemple), et présentées simultanément dans le collinateur. Dans ce mode de fonctionnement de contrôle les termes d'amortissement des ordres sont mis à zéro automatiquement et les informations présentées correspondent aux erreurs de position (écarts oar rapport à la route théorique).

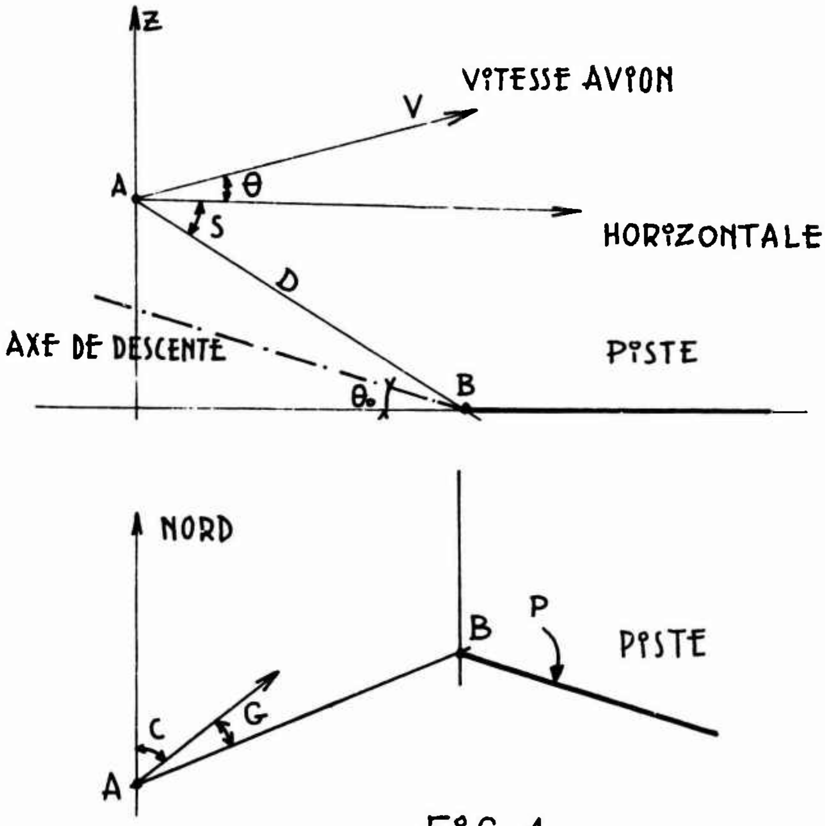
Z
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FIG 1

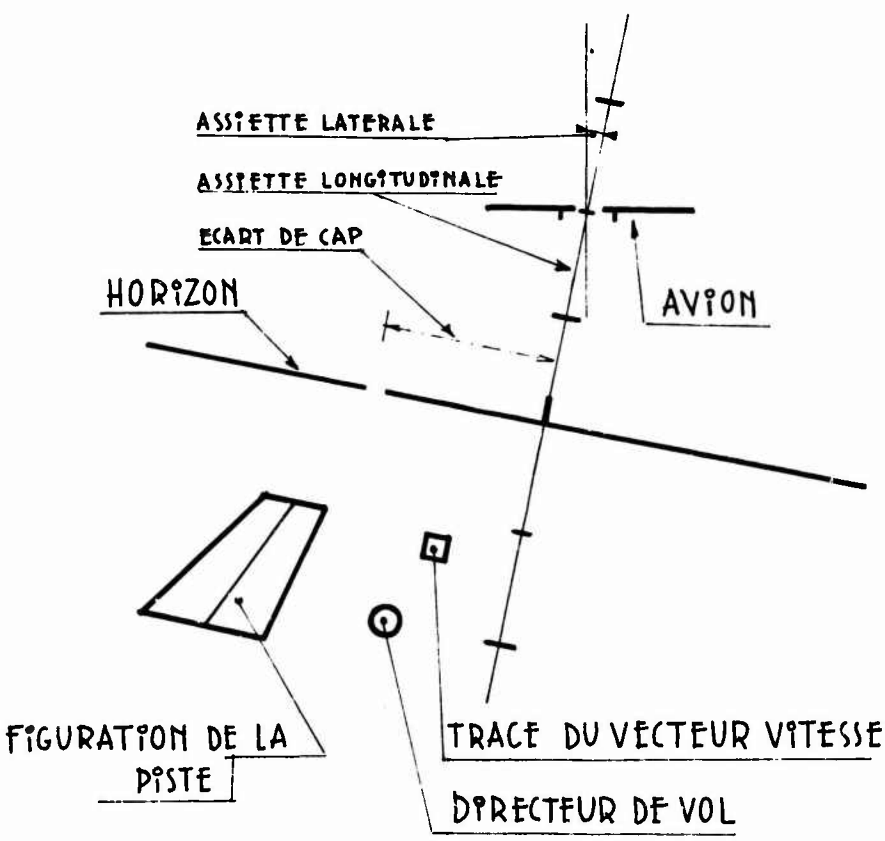
ASSIETTE LATERALE
ASSIETTE LONGITUDINALE
ECART DE CAP
HORIZON
AVION
FIGURATION DE LA PISTE
TRACE DU VECTEUR VITESSE
DIRECTEUR DE VOL

FIG 2

ADVANCES IN V/STOL COCKPIT INFORMATION

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A dilemma confronts the designers of modern V/STOL cockpits. On the one hand they must provide maximum windscreen area, to permit optimization of observation and low-altitude-flight missions. On the other hand they are asked to provide space and display area for new scopes, for bigger displays and for airborne computers. The new information-gathering devices and sensors have exceeded the limits of conventional cockpit design to provide space for their associated visual displays. If new displays are employed they are "tacked on" the side, the bottom, or the top of the panel. The panel itself generally postdates its fixed-wing counterpart by one to two decades. Confirmation of this fact may be obtained by examining almost any helicopter cockpit currently in a military inventory.

The new information which is becoming available can expand the pilot's own ability to "see" in the dark and through obstructions to visibility. The new displays might be dichotomized into directly sensed imaging systems and computer-processed information displays. The former would include television, low-light-level television, forward-looking infrared, direct-view sights, image intensifiers, forward-looking radar, and plan-position- indicator radar. Each of these sophisticated sensors provides its own unique type of information. The latter displays would include computer-generated information, such as the contact-analog display, map displays, and communication or data-link information displays.

Many directly sensed imaging systems have been flight tested in rotary-wing aircraft. It was found, for example, that television displays could be used quite successfully as flight-attitude control displays. With them, pilots could also identify navigational check points and make safe takeoffs and landings in prepared areas. Flight tests with low-light-level television indicated that it had the same advantages and disadvantages as daylight television.

A new helicopter radar display system has been developed at Bell Helicopter Company. The antenna for this system is embedded in a rotor blade. It was flight tested as a navigational display without the use of radio aids to navigation. The experimental flight was over a 48-mile, four-legged round-robin course, traversing both populated and unpopulated terrain. After approximately three hours of training with the radar display, pilots were able to navigate within a corridor of ±1 mile from the desired course. They made corrections for drift, they identified checkpoints, and they made maximum use of pilotage-type cues. All flights were made under simulated instrument conditions.

Computerized displays, such as the helicopter application of the pictorial "contact-analog", forward-looking display have been flight tested and found to provide very promising performance results. In a Bell UH-1B helicopter, pilots were able to takeoff, navigate, approach and land using this display under simulated instrument conditions. Performance was highly correlated with contact or visual-flight performance. With these displays, as well as with the directly sensed image displays, it was noted that a larger number of textural elements on the display would permit better control of the aircraft near the ground. There was universal difficulty in judging depth at very low altitudes, and pilots preferred wide fields of view (40 to 50 degrees) with an exact correspondence with the real world. These displays that were generated by airborne computers were accepted by the pilots with varying degrees of confidence. Other computerized visual displays requiring cockpit space include: plotting-boards with course traces; digital displays that permit the pilot to interrogate the airborne computer regarding position, fuel consumption, time remaining, and optimized alternate courses; and data-link displays that permit intership as well as intraship and air-to-ground communication.

One solution to cockpit and instrument-panel crowding is a multimode display. Such a display could permit switching from one presentation to another. Economy of space would be achieved, but with the possible detriment of limiting the viewing time of any one presentation. A second answer could be a head-up display (HUD) which presents information on a transparent surface through which the pilot can also see the contact world. A third solution could be a head-mounted or helmet-mounted display. This modification of the usual HUD maintains the head-up and the see-through capabilities. Bell Helicopter Company has developed and flight tested an eyeglass system. It has been found to have all of the advantages of the HUD, and several qualities which make it worth noting, including the capability to present stereoscopic images; and the assurance that the pilot cannot inadvertently miss the presentation of emergency lights. In combination with a head tracker and imaging sensors, this system makes it possible for the pilot to scan large areas; thus it provides an effectively large field of view. The pilot can scan the regions beneath and behind the aircraft. His head movements are completely normal and concomitant with his contact flight performance.

The only answer available to the designer of today with respect to the display of new information is to change the conventional means of presentation. He must utilize new techniques of displaying visual information. The human engineering discipline must provide displays which fit the population stereotype, and all engineers who are interested in cockpit presentations must abandon conventional thinking. There is no longer room in the cockpit for many more three-inch or five-inch displays. With respect to human ability to read moving information, seven-inch scopes are small; yet in terms of installation in the cockpit, they are exceedingly large.

Head-up and eyeglass displays seem to offer the next step forward in instrument display. The future may provide presentation of the display information directly on the windscreen. This may be our second step. The age of development in which we live is stimulating. We must answer the challenge of our own technology.

THE DISPLAY OF AERONAUTICAL CHARTS[1]

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Pilots need navigational information displayed in an easily understood form; and there is no more versatile form than the aeronautical chart. They take it as self-evident that their need will be met best by replacing the folded paper chart with a fully-automatic chart display. This paper is a summary of current capabilities in the display of aeronautical charts in the cockpit environment.

More than a dozen different organizations have been developing systems for the automatic display of charts. Three main types of systems are being developed: direct-view displays, projection displays, and kinescopic displays. The main advantages and disadvantages of each type are summarized below. The comments are about the general display types and not necessarily about specific models of a given type.

Direct-View Displays

In a direct-view display, a strip chart, made of paper or mylar, is moved by rollers under a lateral cursor denoting the aircraft. Ordinarily, the strip chart covers the flight corridor only, but area coverage is possible by joining edge-coded strips. (In another type of direct-view display, a servo-driven aircraft symbol moves over a fixed map-card; it is useful mainly in restricted terminal areas.)

The main advantage of roller-map displays is that the pilot is able to write on the chart. Before the flight, he can inscribe his flight plan, tactical intelligence, and map corrections. During the flight, he can note reconnaissance information. After the flight, the chart can be used as a record of the mission, and may include a pen tracing of the track flown. Roller maps are lightweight, and some are small enough to be used as kneeboard displays. They accept standard aeronautical charts, so cartographic support is immediately available.

The main disadvantages of roller maps are that they are usually mission-specific and require laborious preparation. Chart coverage is restricted to a particular flight corridor, so the pilot cannot deviate far from his flight plan. Area coverage and changes in chart scale can be achieved only with extensive preflight preparation. The chart can be displayed only in the course-up position (or for an area-stripped chart, only in the north-up position).

Projection Displays

In a projection display, a microfilm of the chart is rear-projected on a display screen, and the chart image is servo-driven to move with respect to a fixed aircraft symbol. Some projection displays use 35mm or 70mm strip films; others use individual plates or film-chips.

The main advantage of projection displays is that they can provide cartographic coverage over a large operating area. They also can display other types of information, such as checklists, approach plates, and target photographs. Projection displays offer the option of course-up or north-up chart orientation, and can graphically portray command headings (as to programmed way-points). By slewing the image, the pilot can easily obtain bearing or distance measurements to remote points. In operational use, these displays require a minimum amount of preflight preparation.

The main disadvantage of projection displays is that the pilot cannot readily annotate the chart image, so the chart normally will not portray the flight plan (mission overlays are possible, but may not be feasible). Charts cannot be updated with the latest tactical intelligence without preparing completely new microcharts. There is no way for the pilot to mark his chart in flight, and there is no record of the mission after the flight. Projection displays are larger and heavier than direct-view displays. Their effectiveness is tied closely to current capabilities in color microphotography.

Kinescopic Displays

The kinescopic display is the most advanced type. It combines a chart image with a cathode-ray-tube (CRT) image, and is not intended to be solely a chart display. The CRT imagery may be returns from ground-mapping radar or may be electronically generated symbols. There are currently three main display systems: (1) a roller-map transparency is servo-driven over a CRT raster, (2) a chart is optically projected through the tube onto the raster, and (3) a projected chart image and the CRT image are optically mixed and displayed by a field lens or beam combiner. None of these systems is currently operational, so the comments which follow are based largely on theoretical capabilities. There is little information available on the first type, so the comments refer only to the second and third type.

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[1]This paper is based on research supported by the Office of Naval Research, the Naval Air Systems Command, and the Army Electronics Command under contract number Nonr 4218(00). The research is guided by the Joint Army-Navy Aircraft Instrumentation Research (JANAIR) Working Group.

The main advantage of kinescopic displays is that they conserve display space in the cockpit by using the same surface (the CRT raster) for several purposes. The chart image may superpose the ground-mapping radar to aid navigation and target identification. Some annotation of charts can be achieved, within the limits of the CRT symbology. The positions of other vehicles could be displayed, such as other aircraft, mobile targets, and aircraft carriers. Multiple estimates of own-ship position, as indicated by different sources of navigation information, could be displayed.

The main disadvantage of kinescopic displays is that they are heavy, expensive items of equipment, and require substantial power and cockpit space. The viewing angle of kinescopic displays is restricted, and there are many unanswered questions concerning their legibility in the cockpit environment.

Comparisons and Trade-Offs

Any of the display types can accept navigation data from doppler, inertial, air mass, manual, or other sources. And each can help the pilot communicate with the onboard computer to update the navigation system.

Controversies abound, but data are scarce comparing the legibility, reliability, maintainability, operational accuracy, and real costs of the different displays. No systematic study of display legibility has been made. One can guess that the complex kinescopic displays will be the least reliable and most difficult to maintain. Some data on accuracy has been published, but data from different displays are not comparable. Not even the question of cost has been settled. Equipment costs are lowest for the direct-view displays and highest for the kinescopic displays. But "cost-of-ownership" is high for the direct-view displays, because of chart preparation costs and high chart attrition. Until definitive studies are conducted, it is "no-bet" on comparative legibility, accuracy, or cost. In fact, automatic chart displays have not yet been properly tested in field competition with ordinary hand-held charts.

Here is a rough guide for choosing among the alternative modes of automatic chart displays: if the user normally flies well-planned routes (especially repetitive ones), if he needs mission-specific annotations on the chart, and if he must have a lightweight display, then he should favor the direct-view type of chart display. If the user must respond quickly to sortie requirements and has little time for flight planning, and if he needs flexibility in the choice of destinations and maneuvers over a large geographic area, then he should favor the projection type of chart display. If the user needs maximum flexibility of use of the display surface, and if he needs superpositioned data or much dynamic symbology to be displayed, then he should favor the kinescopic type of chart display.

The state-of-the-art in the display of aeronautical charts is still in an aggressive period of growth. Much further research and development is required to improve methods of chart logistics and preparation, to improve color microphotography, and to improve the design of charts for display application.

The Electronic Display of Primary Flight Data

by

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Despite increased automation the amount of information that needs to be presented to the pilots of current military aircraft is constantly increasing. Space for this additional information has to be found either by the utilization of hitherto unused areas or through an increasing use of time-sharing of existing areas. An example of the former is found in one current RAF aircraft, the Harrier, where the space normally occupied by the standard six flying instruments is occupied by an optical topographic display, and the prime display of flight information is on the electronic Head-Up Display. (HUD)

Traditionally associated with gun-sighting this area has in recent years been used for presenting director type information which would assist the pilot in carrying out a specific task such as flying a predetermined height, or glide path, or terrain following. RAE carried out an enormous amount of work on this use of director information and the result has been a form of display that is very easy and natural to follow.

Because of the demands on cockpit panel space however RAE has turned increasing attention to the display head-up of primary flight information such as height, heading, airspeed and attitude. In discussing the problems associated with each of these parameters it must be remembered that several of them interact with each other and the display must ultimately be considered as a whole.

The artificial horizon, displayed head-up, presents the interesting problem of whether it should be coincident with the real world or whether its movement can be scaled down by some amount. Work at RAE demonstrates that for a very manoeuvrable military aircraft there is a strong case for reducing the scaling by a factor of about five. Pilots in general do not like the very active 1:1 artificial horizon although they naturally accept the movement of the real world. This is probably associated with the shortness of the artificial horizon, limited as it is by the optical design of the HUD. For situations where a definite relationship with the outside world is involved, as for example in certain approach and landing displays, then of course a 1:1 scaling is essential. Here however the aircraft is being flown in a deliberately steady condition, the cone of vision is narrowed anyway to a small angle and the overall effect is quite acceptable.

Displaying flight-path-angle instead of attitude provides advantages in some modes of flight, for example in flying straight and level or in landing along a specified glide slope. However it becomes very jumpy in the presence of turbulence and in certain long thin aircraft the lag between stick action and change of vector can lead to Pilot Induced Oscillations. The solution lies in using a mixture of attitude and flight-path-angle such that the display follows change of attitude in the short term but settles out on velocity vector. For a compact military aircraft this can be obtained by lagging the difference between these two values with a time constant as short as 0.2 seconds, but for a transport type aircraft this has to be in the order of 2 to 3 seconds.

The display of height must be considered from the basis of two different requirements. The need to know what the height is can be met surprisingly well by a numerical display. This is compact, uncluttered and ideally suited to an electronic display. As an information source for a control action however it is very poor mainly because it does not instantly provide error and rate of change of error. Trials at RAE have shown average overshoot errors of about 150 feet on climbing to 35000 ft. and 50 ft. on descending to 2000 ft. Although these are not large errors pilots reported quite high workloads and doubted whether they had much spare attention. Putting demanded height as an input to the flight director removes the control function from the height display itself and results in easy and accurate flying.

Very similar criticisms apply to a numerical display of speed (whether indicated, true, or Mach) and for control functions it has been necessary to add a small analogue display of speed error alongside the digits. The control unit for setting both demanded height and demanded speed has been made very simple to operate and is liked by pilots who have flown it.

Heading is another parameter it has not been necessary to show in a 1:1 relationship with the real world. Some degree of anticipation is necessary and RAE has found that a scale length of about $\pm 15^{\circ}$ compressed by a factor of about 5 is quite suitable. Where appropriate a demanded heading bug can be added.

The temptation with all electronic displays is to include more information than is absolutely necessary and this must be guarded against particularly in the head-up case.

Space for the extra displays necessary in a modern complex aircraft can also be found by time sharing display surfaces. Electronic techniques are particularly suitable for this purpose and obvious advantages can be seen in the presentation of navigation, flight management, engine and warning information. This technique is also particularly useful when much of the information is generated in a central digital computer complex.

However, the need for an electronic display head-down of primary flight data is not so obvious. If the information is needed all the time then the time-sharing element is lost and the increased complexity must be justified in some other way. For instance, the equivalent display area might be reduced significantly in size or there might be improved readability and reduction in work load. So far there has not been an example where both of these aims were achieved simultaneously.

If it is acceptable that the flight information may not be needed all the time, possibly because adequate standby instruments can fill in when necessary, then an electronic display surface, carried for some other prime purpose, can profitably be used to present flight data. RAE has been carrying out both simulator and flight trials of experimental forms of such a display and have concluded that although the information from a standard instrument panel can be presented quite clearly in an area only one-fifth the size, nevertheless this is only achieved with an increased pilot workload.

Some of the difficulties are the same as those described above under Head-up Displays and arise from the extreme compactness of the symbols. Others however are peculiar to a head-down display and arise either from human factors or engineering difficulties. For instance, at night with a blacked out cockpit the display appears to become disassociated from its surroundings and to float about. There is a well established physiological explanation for this and the trouble can be overcome by a small amount of red flood lighting. At the other end of the scale, in full sunlight, any electronic display is in danger of being washed out. Using an EHT supply of 15Kv on the cathode ray tube and a 50% neutral density filter for contrast enhancement it is just possible to get a usable display when the amount of symbol writing is restricted to about 10^3 inches per second.

With electron beam velocities generated by such high EHT it is not surprising that the deflection coils and amplifiers have to carry very large currents, possibly even 10 amps if the deflection angles are high, in order to keep the tubes short. This leads one to consider raster scan rather than flying spot displays because of the possibility of using AC deflection and lower powers. Raster scans however are less bright than a spot deflection system and characters are in general not so well formed.

There is therefore still a considerable amount of research needed in this area before one can claim to know the optimum solution.

Engine Control and Instruments Presentation

by

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Introduction

To take full advantage of the higher engine limitations made possible by improvements in materials and manufacturing techniques, it is necessary to run as close as possible to these limitations and, to enable the pilot to handle such engines with a conventional power lever without damaging them, control systems have become more sophisticated. However, the pilot's instrumentation is rarely accurate enough or readable to within the limits required by the engine manufacturer to avoid criticism by pilots who have difficulty in setting up and controlling to these higher engine limitations. This paper puts forward ideas for engine control systems and instrumentation for combat/strike and transport aircraft and recommends further development of reliable automatic controls, computerised engine instrument displays, auto-monitoring and maintenance recorders to reduce the pilot's workload and enable him to perform his operational task more effectively.

Engine Rating, Control and Operation

On many current turbo-jet and turbo-fan engines, the various ratings are generally defined by unique values of high pressure compressor shaft speed (HP r.p.m.) or turbine gas temperature (TGT), which is valid for all flight conditions. Alternatively the engine may be controlled to a tabulated chart value of engine pressure ratio (EPR), which is varied for a given rating as a function of engine inlet total temperature (T1). With both these methods of rating, which are intended to result in constant turbine entry temperature (TET), the thrust decreases progressively with increase of ambient temperature, as shown in fig.1.

The penalty of increasing ambient temperature on aircraft performance can be offset if the thrust is flat-rated to a constant value, which, as shown in fig.1, results in an increasing TET with increasing ambient temperature. The mechanical penalties of high TET and HP shaft speed which would result from flat-rating thrust to the most extreme ambient temperature encountered would be out of proportion to the advantage gained on aircraft performance. Hence, the maximum TET is restricted by means of TGT or HP r.p.m. limits to a level which will only restrict performance under exceptional ambient conditions. The engine is operated to chart values of EPR which are independent of ambient temperature up to the limits of flat-rating, thereafter reducing as TGT becomes the overriding parameter.

There are two philosophies on which the methods of engine control and operation are based; the one requiring the pilot to control the engine manually within the rating limitations for all phases of flight, and the other using limiters and varying degrees of automatic controllers to ease the pilot's workload. The method of rating, control and operation should be related to the role of the aircraft. In the long range transport role, manual control by pilot and engineer to ratings defined by chart values of EPR may be acceptable, whereas in the short haul transport a degree of automatic control is desirable. The pilot of a combat/strike aircraft requires a full throttle operation with complete freedom of handling within simply defined rating limitations and, if the idea of giving him a derated engine is rejected, then limiters and automatic controllers become necessary features of the control system. The aim with future control systems should be to reduce the pilot's instrumentation to a single parameter to indicate the correct level of thrust and safeguard automatically the integrity and reliability of the engine.

Temperature sensing lag in current systems used for measuring T1 and TGT can introduce engine control and handling difficulties. T1 is used to compensate the scheduling of compressor variable inlet guide vanes (IGV's) and bleed valves and, in current combat/strike aircraft capable of rapid acceleration to high forward speeds, T1 lag produces incorrect IGV scheduling when the pilot throttles back, thus affecting compressor stability. The development of sonic-suction thermocouples and research into gas-filled thermophials to replace the current liquid-filled thermophial should alleviate this problem. The type of thermocouple used for measuring TGT also suffers from temperature sensing lag due to the compromise that has to be made between response and robustness and this affects both automatic temperature control systems and pilot's instruments. Research into the application of optical pyrometry to this problem is continuing.

Engine Instruments

Engine instruments should enable the pilot to select any degree of thrust quickly and easily, monitor performance and recognize a malfunction. To gain the full benefits from high performance engines without detracting from engine life considerations, instruments to an accuracy in the order of $\pm \frac{1}{2}\%$ r.p.m. and $\pm$ 3 degrees C. TGT and excellent quick glance readability are required (see fig.2.). The position and layout of engine instrument panels in the cockpit should not adversely affect the readability of individual gauges, which means in the case of the combat/strike aircraft, displaying the primary control parameter on the same eye level and alongside the pilot's flight instruments. In multi-engine transport aircraft, every effort should be made to reduce the number of engine instruments occupying the front panel by selecting the primary control parameter for frontal display and siting the minimum number of monitoring instruments on the overhead or side panels. The development of auto-monitoring and maintenance recorders should facilitate a reduction the number of monitoring instruments required in the cockpit.

As already stated, the pilot is primarily concerned with an indication of thrust and, for a given case, this will be a function of the engine condition selected, flight conditions, air and power off-takes etc., so that the requirement is for the simplest practical means of setting or checking engine performance to obtain the correct level of thrust. Engine r.p.m. and TGT limitations must not be exceeded, in the interests of engine life, and therefore the attraction from the pilot's viewpoint of achieving a consistent thrust and aircraft performance must be weighed against the penalty of excessive duty on engine life.

On conventionally rated engines, when setting to an r.p.m. or TGT there is normally a substantial scatter in thrust due to various factors and, although accuracy in setting to an r.p.m. is quite high, setting to a TGT demands careful attention by the pilot due to thermocouple response time. A more consistent thrust indication may be achieved by setting to EPR or jet pipe total pressure, although with current instrumentation this involves the use of charts and therefore has limited applications. However, the need for charts could be eliminated by the introduction of computerised systems.

In addition to the standard emergency warnings for engine fire etc., certain other malfunctions require immediate pilot action to safeguard the integrity of an engine and therefore warrant the provision of warning indicators. Engine overtemperature is one such malfunction which can occur for a variety of reasons and in spite of automatic temperature controllers; in certain circumstances the overtemperature can occur without warning and the rise in TGT can be extremely rapid. The requirement here is for an audio warning to get the pilot to throttle back immediately and a warning lamp integral with the TGT gauge to identify the engine in trouble.

Emergency Controls

The cockpit controls for dealing with engine fire or failure emergencies should be arranged to give the pilot a single handed action for cutting off the supply of fuel and hydraulics to the affected engine. This can be achieved either by means of an emergency shut-down/fire handle, or by aligning the necessary switches within a slot to guide the pilot's finger through the correct sequence for shut-down and fire extinguishing (see fig.3). Where a shut-down/fire handle is fitted, the correct closing of fuel and hydraulic valves should be indicated to the pilot, but where separate switches are provided for these valve operations, indicators are not required.

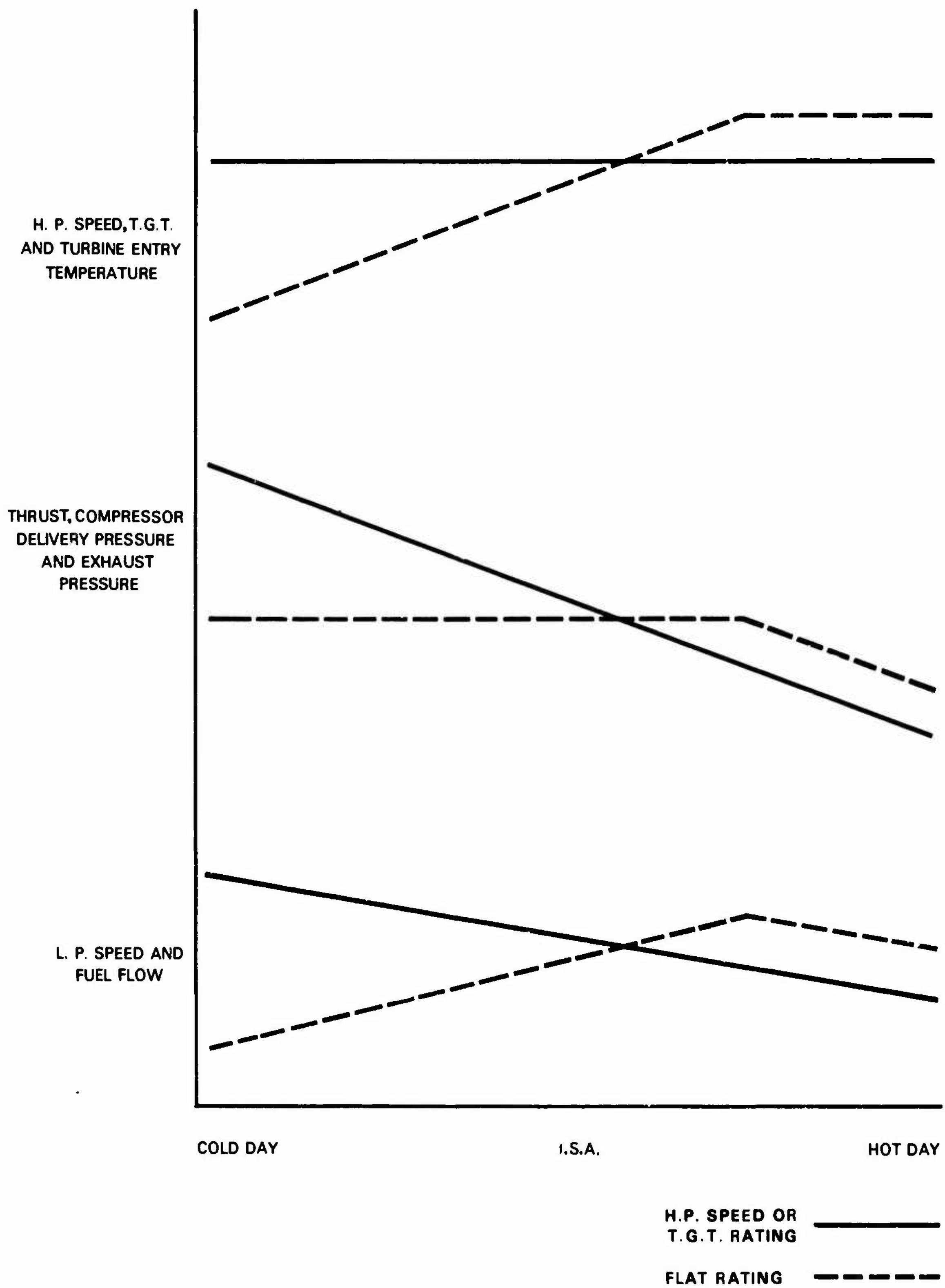
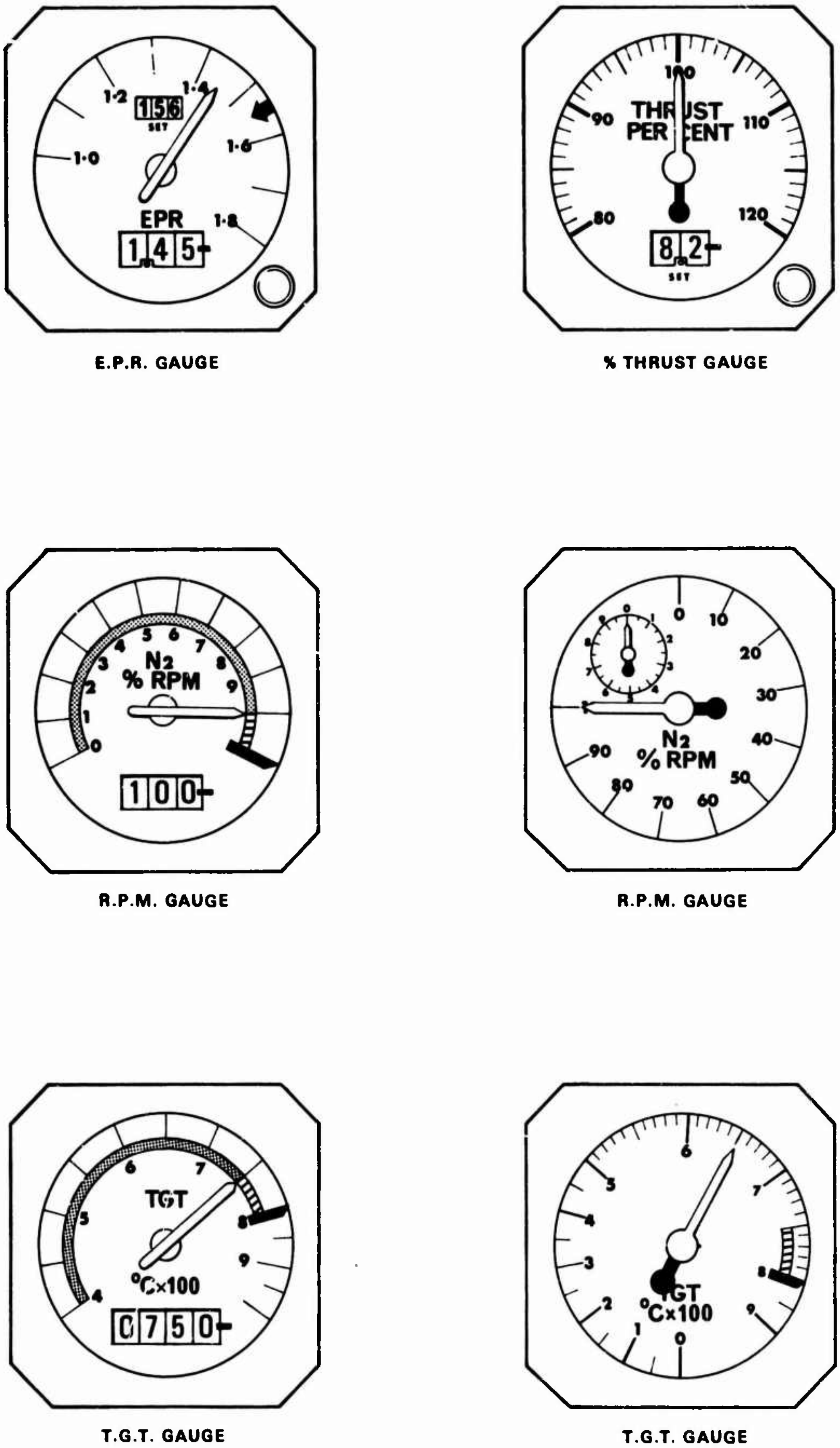


Fig. 1 Comparison of methods of engine rating



All gauges actual size

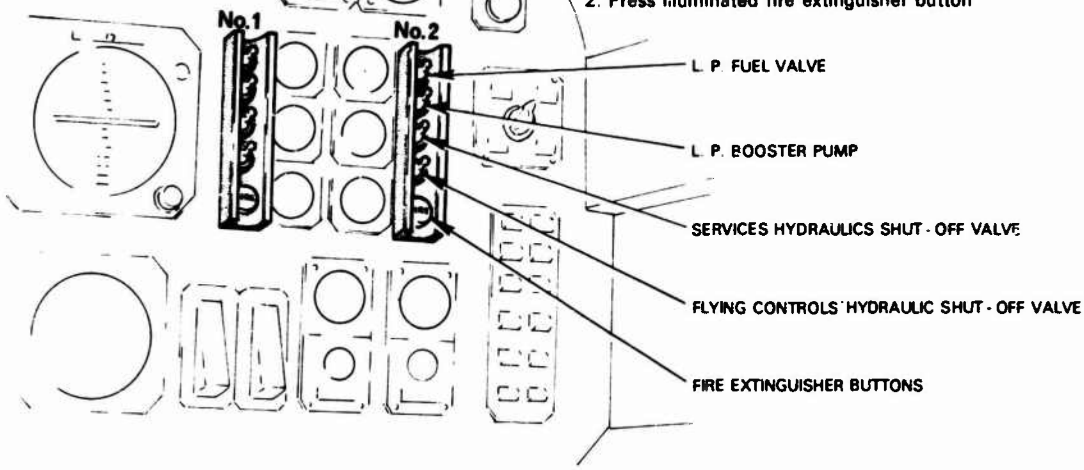
Fig. 2 Cockpit engine instruments readability requirements

INDICATIONS :-

1. Audio and visual warnings from standard warning system.
2. Appropriate 'fire' button illuminates.

ACTIONS :-

1. Appropriate row of switches 'off' from top to bottom
2. Press illuminated fire extinguisher button



INDICATIONS :-

1. Audio and visual warning from standard warning system
2. 'Fire' handle illuminates

ACTIONS :-

1. Pull handle to shut down engine and shut off L. P. fuel and hydraulics
2. Turn handle clockwise to fire first shot of extinguishant
3. Turn handle anticlockwise to fire second shot of extinguishant

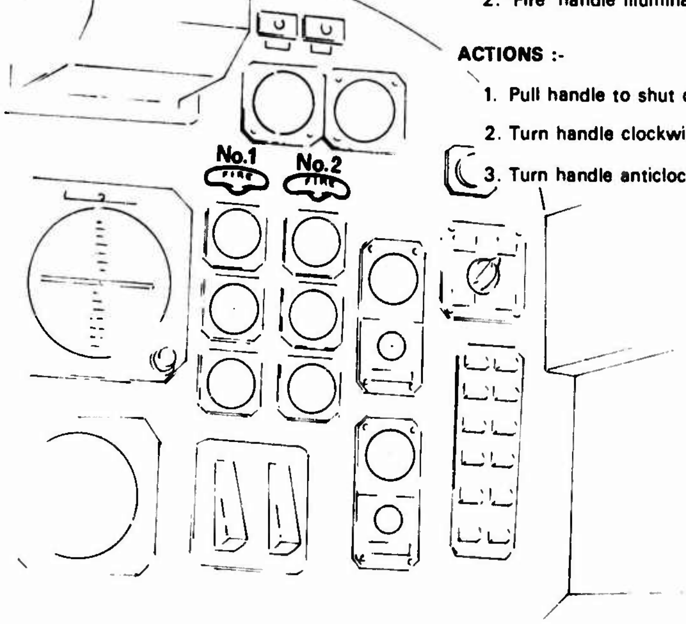


Fig.3 Emergency controls for combat/strike aircraft

UN COLLIMATEUR DE PILOTAGE (A HEAD UP DISPLAY)

P.J. DELIAC - Ingénieur Commercial CSF-178, bd G. Péri (92) Malakoff

1. INTRODUCTION

Le pilotage des avions de ligne devient de plus en plus complexe.

Parallèlement, les équipements de bord mis à la disposition du pilote sont de plus en plus évolués. Toutefois, dans la gamme de ces équipements, on peut constater l'existence d'une lacune en ce qui concerne la présentation des données nécessaires au pilotage, et qui permette soit la surveillance des systèmes de pilotage automatique, soit un pilotage manuel de qualité comparable, en toutes circonstances.

Le collimateur de pilotage doit combler cette lacune.

2. PHILOSOPHIE DU SYSTEME

Les ordres de pilotage sont matérialisés par un directeur de vol (ordres de facteur de charge et de roulis) ; le roulage au sol est dirigé par un directeur de roulage distinct. Les opérations séquentielles sont signalées par des voyants colorés (par exemple : en descente sur le faisceau I.L.S., puis arrondi à 50 pieds, annulation de la dérive à 15 pieds etc...).

Parallèlement à cet affichage d'ordres, les données instrumentales ayant servi à leur élaboration sont présentées par un affichage distinct : écarts I.L.S., radio-altitude etc... L'attitude de l'avion (assiette et roulis) est également représentée.

Toute la figuration est collimatée (projection à l'infini) dans le champ visuel du pilote, superposée au paysage extérieur.

3. AMELIORATIONS APPORTEES PAR LE COLLIMATEUR DE PILOTAGE

Après plus de 1 000 heures d'essais au Centre d'Essais en Vol de Brétigny, les avantages énumérés ci-après ont été obtenus :

- Avantages obtenus par rapport aux instruments classiques d'un tableau de bord :

  . Meilleur rendement dans l'utilisation des instruments (synthèse continue des principales données de pilotage)

  . Précision et sensibilité d'affichage très supérieures (pas de dégradation des informations présentées au pilote)

  . Moindre fatigue du pilote, qui n'a plus à "échantillonner" ses instruments, tout en veillant à l'extérieur.

  . Surveillance facile du bon fonctionnement du pilote automatique, grace à la présentation simultanée, et indépendante, des réactions du pilote automatique, de l'attitude de l'avion, et des données instrumentales.

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- Avantages propres à la technique du collimateur

  . Approche et atterrissage V.M.C., en suivant un axe de descente à pente constante ; le pilotage "à pente constante" est rendu possible par la superposition de repères collimatés sur l'entrée de piste, sans infrastructure spéciale au sol.

  . Décollage et atterrissage en opérations de catégorie III (le directeur de roulage permet de garder l'axe de piste).

  . Veille extérieure continue, à travers la figuration du collimateur.

  . Accomodation visuelle maintenue à l'infini.

- Amélioration de la sécurité en vol

  Cette amélioration résulte :

  - d'une veille extérieure ininterrompue,

  - de la surveillance continue des principales données de pilotage,

  - de la diminution de la fatigue du pilote,

  - de l'aide apportée à l'atterrissage V.M.C. en l'absence d'infrastructure au sol.

- Amélioration de l'instruction des pilotes

  Le collimateur monté sur avion ou sur simulateur, avec caméra d'enregistrement, permet de déceler avec précision et de restituer les réactions instantanées d'un élève-pilote.

4. CONCEPTION DU COLLIMATEUR DE PILOTAGE

L'équipement doit être susceptible de recueillir toutes les données des équipements de bord et de les présenter clairement et sans ambiguïté au pilote.

- Recueil des données :

  Effectué dans une "boîte d'adaptation" électronique, de conception modulaire (modules interchangeables pour chaque équipement).

- Formation d'image :

  Deux solutions sont possibles :

  . tube cathodique avec élaboration électronique des symboles

  . réticules électromécaniques, asservis en position.

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Après étude, la solution des réticules asservis a été retenue.

- Système optique de collimation :

Il assure la projection collimatée de la figuration. Il doit en donner une vision binoculaire confortable (grande pupille optique, obtenue par l'emploi de lentille de collimation à large diamètre).

- Sécurité de fonctionnement :

L'équipement est opérationnellement sûr ("fail operational"), par l'emploi de 3 réticules indépendants et la redondance des circuits critiques.

La M.T.B.F. dépasse 2 000 heures.

Le bon fonctionnement est vérifié par 2 circuits distincts de contrôle :

. Contrôle global instantané "pousse-bouton".

. Contrôle intégré permanent auto-vérificateur, portant sur le collimateur et les équipements associés.

5. CONCLUSION

Le collimateur de pilotage est un instrument d'une nouvelle génération.

En pilotage automatique, il permet de garder le pilote dans la "boucle" de pilotage ; il permet aussi un pilotage manuel d'aussi bonne qualité en toutes circonstances, en particulier lors d'atterrissages V.M.C. sur des terrains dépourvus d'infrastructure.

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